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ORIGINAL ARTICLES.

I.—The Augen Gneiss and Moine Sediments of Ross-shire.

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(WITH A TEXT-MAP.)

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IN the centre of Ross-shire, to the west and north-west of Ben Wyvis, there are large intrusive masses of granite gneiss lying in the midst of the sedimentary Moine schists. They have a N.N.E. strike and extend over a tract of country about 20 miles in length, from Loch Luichart, near Garve Station (Dingwall and Skye line), to Carn Bhren, within 3½ miles of Ardgay Station (Inverness and Wick line). A coarse augen gneiss with large elliptical eyes of pink orthoclase or perthite, sometimes 2 inches long, is the principal rock, but a finer-grained granite gneiss also occupies considerable areas, especially in the region of Carn Chuinneag (see Map, Fig. 1). Boulders of the augen gneiss have been widely distributed by ice, and are common on the shores of the Moray Firth, etc. For that reason the "Inchbae augen gneiss" has long been familiar to geologists, though little was known about the parent mass, except that gneisses of this type were exposed on the high road between Garve and Ullapool, particularly in the lower part of Strath Rannoch.

Since 1900 the work of the Geological Survey has proved this augen gneiss to be one of a number of foliated intrusions, perhaps originally all parts or offshoots of a single laccolitic mass, surrounded by an aureole of hornfelses in which the Moine sediments are intensely contact-altered, and have in large measure escaped the subsequent dynamic metamorphism which has elsewhere over a vast area converted them into the great series of schists and gneisses that are generally known as the Moine Series. Elsewhere in all their extent from the north coast of Sutherland to the Ross of Mull these Moine rocks are paraschists and paragneisses, generally of highly metamorphic types, but in this aureole they retain their original bedding and clastic structures in singular perfection. It has been proved that when the Moine sediments were invaded by the granitic rocks of this region they were sandstones and shales of quite normal character; and much light has been thrown on the history of the district and the manner in which both igneous and sedimentary rocks acquired their metamorphic structures. The one-inch map of this country (sheet 93) is now in

preparation, and is to be accompanied by a memoir in which the facts will be stated in some detail, but we propose to give a brief summary of the principal results with an outline of the evidence, believing that the conclusions are of general interest to geologists.

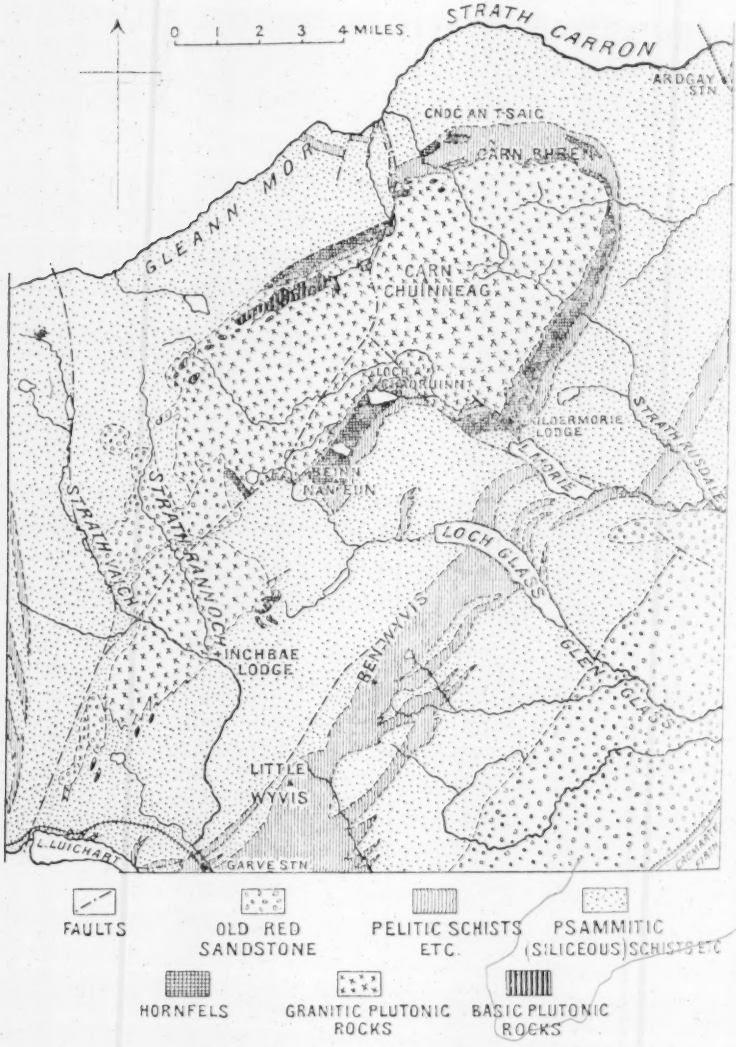


FIG. 1. Map of the Augen Gneiss District of Ross-shire.

The relations of the chief masses of plutonic rock are indicated in the accompanying map (Fig. 1). It will be seen that the Inchbae outcrop of granite gneiss is about 5½ miles long and 3 broad.

Separated from the N.N.E. end of it by a space of 1¼ miles, most of which is occupied by Old Red Sandstone of later age than the granite, is the much more extensive plutonic mass of Carn Chuinneag, 12 miles long and 4 or 5 miles broad, which includes a considerable variety of orthogneisses. On the south-west side of the Inchbae mass a group of smaller detached outcrops of augen gneiss extend several miles in a south-west direction as far as Loch Luichart, and are represented also on the west side of a big fault, striking N.N.E. on the west side of this loch.

That the augen gneiss was once a porphyritic granite is proved in several ways. In some places the large phenocrysts of orthoclase preserve their original idiomorphic outlines and are surrounded by a granitic matrix, in which the original grains of quartz have not suffered granulitization. The surrounding hornfelses are invaded by tongues and veins of granite which have undergone very little deformation. At the junctions in some places, as at Kildermorie Lodge on the south-east side of Carn Chuinneag, the margin of the granite is filled with immense numbers of angular inclusions of baked sediment (garnetiferous biotite hornfels, etc.). Moreover, as already stated, there is an aureole in which certain sediments, elsewhere represented by the Moine schists, have the composition and structure of hornfelses derived from impure sandstones and arenaceous shales.

Within the intrusions various types of plutonic rock may be found. Towards the north-west margin of the Carn Chuinneag mass there are some outcrops of dark-green basic rocks, which have been proved to be gabbros (without olivine) and augite diorites. Others are quartz diorites, and there are also more acid types which correspond to tonalites and hornblende granites.

In some places the basic rocks, like the porphyritic granite, are nearly free from foliation, and show their original structures fairly well preserved; elsewhere all these rocks have been converted by movement after consolidation into amphibolites, hornblende schists and hornblende gneisses. The basic rocks occur in relatively small amount, and are entirely in the form of inclusions, large or small, surrounded and veined by the granite. The field evidence proves that they are earlier than the granite, and it is probable that they originated by the differentiation of an acid magma in much the same way as the basic rocks of Garabal Hill and of so many other intrusions of the Newer Granite Series in the Scottish Highlands and the Southern Uplands.

Towards the centre of the Carn Chuinneag mass there are several areas of ægirine riebeckite gneiss, a rock extremely rich in alkali felspars, with quartz and soda-pyroxenes and amphiboles. We may mention also the remarkable occurrence of masses of magnetite and cassiterite (containing sometimes nearly 16 per cent. of tinstone) on the north-west shoulder of Carn Chuinneag; these are accompanied by a peculiar dark biotite gneiss with large rounded garnets and much albite. This mineral paragenesis is almost unique, and the origin of this ore-deposit is a problem very difficult of solution. The finer-grained granite gneiss of Carn Chuinneag, in which the ægirine

riebeckite gneiss and the albite gneiss occur, is a biotite gneiss. Other fine-grained gneisses, which contain muscovite but little or no biotite, probably represent foliated aplites.

The history of the foliation in the orthogneisses is intimately connected with the history of the foliation in the schists, but in the former there is very complete proof that this structure was developed after the igneous rocks were quite solid. Although sometimes nearly normal granites, gabbros, etc., they generally show some indication of deformation. In the porphyritic types the phenocrysts of quartz and felspar are usually less sheared than the matrix, which must consequently have been solid before the rock was crushed. The quartz breaks down more readily than the felspar, and every stage of granulitization can be made out. Where a plexus of acid veins permeates the basic rocks, the latter, though older, are never in a different state from the granites, that is to say, there is no evidence that the basic rocks were foliated before the granite invaded them (as is often seen in the Lizard district). Sometimes a complex of this sort has been pulled or rolled out into a banded gneiss, not unlike some types of the Lewisian, but both acid and basic rocks are in the same state, and the derivation of such a gneiss from an intrusion breccia can be followed step by step in the field. The crushing and consequent development of foliation vary considerably in intensity from point to point, and sometimes suddenly along certain lines of thrust or special shearing, which frequently strike N.N.W. But for the most part the foliation maintains the N.N.E. trend, which is characteristic of the Moine schists of this area also, and often strikes across the boundary with the schists. Another fact of especial significance is that the big masses of granite, and also the thin veins in the paraschists, are in a number of places foliated across their length, with the same foliation as marks the rocks around them.[1]

The sedimentary schists that form the country rock are arranged in a fold with its major axis striking N.N.E., nearly parallel to the lengths of the granite masses, and away from the augen gneiss they differ in no respect from Moine schists and gneisses in other parts of Scotland. We may distinguish two main types—(1) the siliceous or psammitic schists and gneisses, with both muscovite and biotite, (2) coarse pelitic or semipelitic garnetiferous mica schists. Thin bands of zoisite-hornblende gneiss and of granulite with prisms of zoisite nearly an inch long are also found. The whole of these schists, as is well known, were originally sedimentary rocks (arkoses, shales, marls and sandstones), and with them occur dark hornblende chlorite schists which represent basic igneous masses in a state of complete metamorphism. In these rocks the traces of original clastic or igneous structures have often been effaced, though relics of pebbles of quartz and felspar in the psammitic gneisses locally betray their sedimentary origin; the quartz pebbles are often dragged out into long ribbons. There are moreover in these Moine rocks no minerals of thermal origin

[1] This was first made out by Dr. B. N. Peach at the edges of the Loch Laichart outcrops, and was mentioned by him in the *Summary of Progress of the Geological Survey* for 1898, p. 9.

(such as andalusite) and no hornfels structures. Recrystallization and the development of foliation have converted them into schists and gneisses, typical products of regional metamorphism.

But in certain areas around the edge of the granite, in a strip of country that varies in width up to about a mile, quite other types of rock are found. Many of them are fine-grained, flinty-looking, with a well-marked banding due to bedding. From the abundance of black mica in very small plates these rocks have a bluish leaden colour. They are hard and splintery, breaking in any direction, and sometimes contain rounded garnets as large as peas, or prisms of andalusite half an inch in length. When first they were encountered these rocks were recognized by Dr. Peach as hornfelses, typical thermo-metamorphic products of the action of the granite intrusion on sandy shales. Nothing like them had been previously seen in any part of the Moine country.

In the rocks of the Southern Highlands, however, various instances are known where hornfelses retain in exceptional perfection the original characters of sedimentary rocks. On the north-west of the Ben Vuroch augen gneiss (a foliated granite by no means unlike that of Carn Chuinneag) Mr. Barrow had previously detected pyroxene hornfelses (calc-flintas), fine-grained, with bedding preserved. Near Loch Awe and in Knapdale and Islay thin bands of hornfels have been frequently observed at the margins of epidiorites that were once intrusive dolerites.

The minerals of the banded hornfelses are quartz, felspar and brown mica. Very generally they contain garnet, and sillimanite also is common as small prisms densely clustered. Pseudomorphs of andalusite are found only along certain bands, sometimes in the form of typical chiastolite with the black cross-shaped markings, sometimes in large cumorphic prisms; but the mineral is always replaced by white mica and kyanite. Pseudomorphs after cordierite have been seen in one or two rocks, and there are also compact pyroxene hornfelses derived from the marl-bands (calcareous shales) that give rise to the zoisite hornblende granulites under other conditions. The fine biotite hornfels is often 'spotted' with small spots, exactly in the same manner as a spotted slate from the aureole of a Cornish granite.

The banding of the hornfels is due to the alternation of laminæ rich in quartz with others more rich in biotite. The quartzose bands often contain minute pebbles of rounded quartz; sometimes they have the structure of argillaceous sandstones, well preserved in every detail. On the surfaces of certain layers there are markings strongly suggestive of sun-cracks and ripple-marks, and others which may possibly represent worm-tubes. The banding is evidently due to bedding, and the rocks were originally fine laminated arenaceous shales. This has been confirmed also by chemical analyses. Where the contact alteration is most intense or the rock has been very argillaceous the clastic structures, as might be expected, are less obvious, but they are never absent.

It is to be noted that in the least sheared hornfels the bedding is generally lying at gentle angles, and over wide areas near Kildermorie and south of Loch Chaoruinn it is dipping at right angles to the general direction of the bedding and foliation in the neighbouring

schists. In the Loch Chaoruinn district the rocks are further arranged in the form of a syncline, traceable by means of one of the andalusite bands mentioned above. This syncline is truncated on the one hand by the granite margin and on the other by the schistose rocks. The pelitic mass in the areas just referred to is in the condition of hornfels, except along a narrow belt in contact with the granite, and at its outer margin next the psammitic schists, in both of which positions it has generally undergone considerable shearing. The pelitic outcrop, which originally must have been a single mass of shale or sandy shale, is now at some points an unsheared hornfels, while at others it has been converted into a garnetiferous mica schist, with folds and foliation striking at right angles to the bedding in the hornfels.

As we proceed outward from their centres the masses of hornfels in other areas also can usually be traced passing into mica schist, whether we move towards the granite or away from it. There are many intermediate stages between typical hornfels and typical mica schist, one of the best marked being a fine greyish rock full of small micas, white and black. This may be called the stippled schist, and often forms a belt next to the granite. It has more mica than the hornfels, especially muscovite, which has developed at the expense of felspar. The garnets of the hornfels persist, but the sillimanite and andalusite disappear. The latter passes first into kyanite, and pseudomorphs of kyanite after chiastolite, retaining the original outlines and structure, though consisting only of aggregates of small divergent prisms, may often be seen. These we take to be illustrations of the efficiency of pressure in substituting that form of the silicate of alumina which has the highest specific gravity and least molecular volume. Later the andalusite crystals are greatly bent and puckered and converted into white mica, the large prisms being then drawn out into pale films that lie along the cleavage.

The stippled schists are fissile, as their micas have a parallel orientation that is lacking in the hornfels. This is a new structure, namely, foliation. The direction of orientation often crosses the bedding, and as the foliation develops the sedimentary banding gets less evident, though still persisting. The rocks are being sheared and interstitial movement is taking place; the dragging out of the andalusite proves this and also the deformation of the quartz pebbles. In the other schists, which are more coarsely crystallized than the stippled schists, the mica plates get longer and larger; felspar vanishes almost completely, though sometimes a little albite makes its appearance. The ultimate product is a mica schist with each plate of mica a hundred to a thousand times larger than those of the hornfels. We note the operation of three processes closely connected—(1) interstitial movement, (2) recrystallization with orientation of the micas perpendicular to the directions of stress or along the planes of movement, (3) continued growth in size of the characteristic minerals of the schist. Here again chemical analyses have proved that the coarse mica schist was originally the same rock as the fine blue splintery hornfels. It is probable, however, that the extreme outer margin of the pelitic band near Kildermorie never was in the condition of hornfels, but was converted directly into mica schist.

The unsheared hornfels is never found more than a mile from the granite margin. Round the granite the 'aureole' is not continuous, but is broken at certain places by the intervention of shearing. It should also be stated that at the south-west margin of the Carn Chuinneag mass and around most of the Inchbae mass the granite is in contact with psammitic schists, in which little evidence of contact alteration has been detected.

In the Moine rocks, at a distance of a mile or more from the granite, there is great uniformity in the character of the foliation. The explanation that suggests itself is that these sediments were soft and readily yielded to folding, while free internal movement gave full play to the forces of recrystallization by which schists are produced. Some parts of the granite mass and many parts of the hornfelsed rocks of the aureole were, on the other hand, more resistant to folding, and considerable blocks of them moved *en masse* and retained their original structures, while in adjacent portions there was much internal shearing, with consequent production of cataclastic structures and development of schistosity.

The hornfels has been sheared decidedly less than the granite, and its original characters are in better preservation. The physical structure of these rocks seems to give them a remarkable cohesion and toughness under the conditions of pressure and folding that occasion metamorphism of the 'regional' type. This is no doubt due to their finely crystalline state, the perfect interlocking of their minerals, which, having grown in a solid mass, often enclose one another; and especially to the development of authigenic new felspar in the interstices between the sand-grains, cementing them together into a very rigid mass. It seems clear, from the facts known, both in Easter Ross, Ben Vuroch, Knapdale, etc. (see p. 341), that fine hornfelses are rocks from which schists are not readily formed.

Mr. Barrow has advanced the hypothesis[1] that the Ben Vuroch hornfelses were preserved because they were sheltered behind a large resistant mass of granite. But at Carn Chuinneag the facts show clearly that the hornfels is a much more resistant rock than the granite; moreover, hornfelses occur on all sides of the granite, not only on the north-west, which was the lee side, but also on the south-east, from which the pressures came.

It is obvious that the sediments and hornfelses were solid when they were sheared and converted into mica schists, and the phenomena observable at the junction of granite and hornfels render it equally clear that the igneous rocks also were thoroughly crystallized before the movements began. If the hornfels at the junction is quite free from foliation—a rare condition—the granite also shows its igneous structures well; but if the hornfels has passed into a mica schist the igneous rock is always gneissose. This is especially noticeable in the fine granite veins that penetrate the schists; they cut the bedding clearly in the banded hornfelses, and in the mica schists they have a foliation that corresponds with that of the schists and often crosses the veins from side to side.

[1] "The Geology of the Country round Blair Atholl, Pitlochry, and Aberfeldy": Mem. Geol. Surv., 1905, p. 93.

Still more convincing evidence, if that were possible, that the schists and gneisses of this country were developed from solid rocks by pressure and movement is furnished by a series of remarkable crush-zones that traverse both igneous and sedimentary rocks alike. Some of these were described by Mr. Clough in 1902,[1] but the main facts may be recapitulated here.

After the movements that produced the main foliation of the district had come to an end, and the rocks were for the most part in the same state as they are at present, a group of basic dykes (olivine dolerites) were injected along a system of fissures that have mainly a N.N.W. trend. Thereafter movements again set in (posthumous movements), but on a lesser scale and more local in their distribution. They folded the previous foliation in the gneisses and schists, and their action appears in a concentrated form along certain crush-zones or belts of secondary shearing, which are narrow strips running in various directions, but often nearly at right angles to the strike of the general folding in the Moine rocks. Where the hornfels is involved in one of these crush-zones it may be changed within a few feet into a lustrous mica schist. When a crush-zone passes from the schists into the granite gneiss, the latter also becomes highly schistose with a large development of new white mica. In the granite gneiss the vertical dolerite dykes were apparently weak rocks that easily yielded to pressure, for secondary shear zones rather commonly take the line of these dykes. In that case the basic rock assumes the form of a typical hornblende schist, rather fine-grained but perfectly foliated and completely metamorphic. The foliation in the crush-zones is parallel to the length of the zone, and consequently is often at right angles to the foliation of the Moine rocks and the granite gneiss. At the edges of the hornblende schist dykes a new foliation makes its appearance in the granite gneiss. Most perfect at the junction with the dyke, it fades away in a few inches. It is evidently a superinduced structure which masks the original foliation of the acid rock, yet it is often very highly developed, and thin slabs may be split off from the gneiss at the edge of the basic dykes with a structure which may be described as mylonitic at a considerable angle to the foliation in the same rock only a couple of feet away.

The fine-grained structure of the dykes proves the granite to have been cold at the time when they were injected, and the development of a new foliation in the gneiss that forms the walls of the dykes proves equally clearly that the main foliation was already developed before these rocks were sheared. When the later movements supervened the granite compressed the dykes as a vice grips a piece of soft iron. The weaker metal gives way and is deformed, but before its rigidity is overcome the jaws of the vice also suffer.

We believe that the granite gneiss and its aureole furnish us with an undoubted example of pure dynamic metamorphism. All the rocks involved—igneous, sedimentary, and the contact-altered hornfelses—were free from foliation when the movements began, and when the movements came to an end they were, in varying degrees of perfection,

[1] *Summary of Progress of the Geological Survey* for 1902, p. 150.

schists and gneisses as we find them now. This implies a similar history for the whole Moine system of the North of Scotland. The age of these rocks and the period or periods of movement that produced the foliation are not satisfactorily established, but that the movements occasioned the metamorphism is sufficiently clear. There may be, and probably are, in the Scottish Highlands orthogneisses that have a different history from the Carn Chuinneag granite gneiss. Mr. Barrow has shown reason to believe that near Blair Atholl some orthogneisses have structures developed in them by pressures acting during consolidation.[1] Similar types of gneiss are believed by Dr. Flett to occur in the Lizard Peninsula. But in the granite gneisses of Ross-shire no structures have been met with that cannot be explained as occasioned by the action of orogenetic pressures on normal igneous rocks completely crystallized.

II.—Note on two Cephalopods [*Pachydiscus farmeryi*, n.sp., and *Heteroceras reussianum* (d'Orbigny)] from the Chalk of Lincolnshire.

By G. C. Crick, Assoc. R.S.M., F.G.S., British Museum (Natural History).[2]

(PLATE XXVII.)

THE British Museum collection has lately been enriched by two Cephalopods from the Chalk of Lincolnshire that seem to be worthy of notice; one being a new species of *Pachydiscus* (*P. farmeryi*), the other being referable to the genus *Heteroceras*.

1. Pachydiscus farmeryi, n.sp. (Pl. XXVII, Figs. 1, 2.)

Diagnosis—Shell (internal cast) discoidal, umbilicated; greatest thickness at about two-fifths of the height of the whorl from the suture, about three-tenths of the diameter of the shell; height of the outer whorl about three-eighths of the diameter of the shell. Whorls few, exact number unknown, probably about five; inclusion about one-half; umbilicus not very deep, about two-fifths of the diameter of the shell in width, exposing the inner whorls. Whorl broadly oval in transverse section, a little higher than wide; indented to about a quarter of its height by the preceding whorl; periphery broadly rounded, ill-defined; lateral area rather inflated, not sharply defined from the umbilical zone; umbilical zone convex, imperfectly defined from the lateral area. Body-chamber occupying fully one-half of the outer whorl; aperture not seen. Details of chambers and of suture line imperfectly known. The surface of the outer whorl with about nine curved, raised, obtusely-rounded, forwardly-projected ribs, each being raised on the lateral area into a transversely-elongated node, which, in the course of the outer whorl, passes from the vicinity of the umbilical margin to about the middle of the lateral area, each of the last four or five ribs passing into a longitudinally-flattened tubercle at the margin of the peripheral area; the spaces between these principal ribs occupied, certainly on the peripheral area and

[1] "The Geology of the Country round Blair Atholl, Pitlochry, and Aberfeldy": Mem. Geol. Surv., 1905, pp. 98–100.

[2] Published by permission of the Trustees of the British Museum.

possibly also on part of the lateral area, by five or six finer ribs, which cross the peripheral area in an orad-convex curve; near the anterior end of the outer whorl there is, behind each pair of flattened tubercles at the edge of the periphery, a similar but smaller pair at about two-fifths of the distance between one pair of large tubercles and the next succeeding pair; the inner whorl with large widely-spaced obtusely-rounded nodes.

The holotype (Figs. 1, 2) is a somewhat distorted natural internal cast of rather more than one and a half whorls; the innermost whorls are wanting. The fine ribs are specially visible on the peripheral area of the first and last portions of the outer whorl, but the surface of the specimen is not sufficiently well preserved to show if these were continued over the lateral area. The surface of the fossil generally is too imperfectly preserved to show the course of any of the septal sutures, although septa appear to have been present throughout fully two-thirds of the outer whorl. The specimen, which now forms part of the National Collection [B.M. No. C. 12,220], was collected by J. R. Farmery, Esq., after whom the species is named. Its measurements are: greatest diameter, 91·5 mm. (100); width of umbilicus, 37·5 mm. (41); thickness of outer whorl, 27·5 mm. (30); height of outer whorl, 34·75 mm. (38); ditto above preceding whorl, 23·5 mm. (25·6).

Horizon and Locality.—Turonian, zone of *Holaster planus*: Boswell, near Louth, Lincolnshire.

Affinities and Differences.—The specimen greatly resembles Schlüter's *Ammonites auritocostatus*,[1] but that species, recorded by its author from the *mucronata* beds (Senonian) in Hanover, is more narrowly umbilicated than the English form: the specimen from near Darup, Westphalia, which Schlüter[2] figured and doubtfully referred to this species, but has been named by A. de Grossouvre[3] *Pachydiscus ambiguus*, and recognized by him in the Middle Campanian at Tauillard (Charente), France, is not only more narrowly umbilicated but a more compressed shell, the lateral area lacking transversely-elongated nodes, whilst between each pair of nodes at the margin of the periphery there are two or three fairly-prominent simple ribs extending uninterruptedly from the umbilical margin over the sides and the peripheral area. It is also more widely umbilicated than the example from the neighbourhood of Gan, near Pau (Basses-Pyrénées), that Seunes[4] referred to Schlüter's species, but which Grossouvre[5]

[1] C. Schlüter, *Beitrag zur Kenntniss der jüngsten Ammoneen Norddeutschlands*, 1867, p. 20, pl. iii, fig. 2 (*Ammonites Proteus*, a name preoccupied by d'Orbigny). C. Schlüter, "Cephalopoden der oberen deutschen Kreide," pt. ii: *Palæontographica*, Bd. xxi, Lief. ii, 1872, p. 70, pl. xxii, figs. 4, 5 (not 6, 7 = *Pachydiscus ambiguus*, A. de Grossouvre).

[2] C. Schlüter, "Cephalopoden der oberen deutschen Kreide," pt. ii: *Palæontographica*, Bd. xxi, Lief. ii, 1872, p. 70, pl. xxii, figs. 6, 7.

[3] A. de Grossouvre, *Mém. Carte géol. détaillée de la France: Recherches sur la craie supérieure.*—Pt. ii: *Les Ammonites de la craie supérieure*, 1893, p. 198, pl. xxix, fig. 3.

[4] J. Seunes, *Recherches géologiques sur les terrains secondaires et l'éocène inférieur de la région sous-pyrénéenne du sud-ouest de la France (Basses-Alpes et Landes)*, 1890, p. 239, pl. viii, fig. 4.

[5] A. de Grossouvre, op. cit., p. 197.

identifies with *Pachydiscus Sturi* (Redtenbacher)[1] from the so-called Gosau Beds at Muthmannsdorf, Austria, a species which he also records from Mas de Blas Giner, near Alcoy (province of Alicante), Spain; in all cases in the Upper Senonian.

The Lincolnshire specimen, although belonging to this group of forms, is easily distinguished by its wide umbilicus. Occurring at a lower horizon than the other species mentioned, namely, in the zone of *Holaster planus*, one would naturally expect to find a more widely umbilicated form.

2. Heteroceras reussianum (d'Orbigny).[2] (Pl. XXVII, Fig. 3.)

The specimen which seems to be referable to d'Orbigny's genus *Heteroceras* was obtained by the Rev. C. R. Bower from the *Holaster planus*-zone at North Ormsby, Lincolnshire. In this genus there is a turreted portion as in *Turrilites*, but the terminal portion of the shell is bent into the form of a hook. The present specimen (Fig. 3) appears to be a portion of the terminal hook of an example lying upon, and with one end partially imbedded in, a small block of chalk, the portion on the right-hand side being the anterior or apertural end. Close to this end of the hook there is a portion of a whorl of a turreted Cephalopod (marked *a*) that possibly originally belonged to the same specimen as the larger fragment. The hook, which has a total length of about 110 mm. as measured along the median line of its periphery, does not lie quite in one plane, but has a double curvature; this character is exhibited more especially by the posterior portion of the hook that is only partially exposed and is shown on the left-hand side in the accompanying figure, this limb being apparently the one by which the hook was attached to the turreted portion of the shell, and therefore the younger portion of the hook. The transverse section of the last portion of the shell (the part on the right-hand side in the accompanying figure) is a compressed oval, the ventro-dorsal and transverse diameters being 25 and 17 mm. respectively; the cross-section of the other limb cannot be ascertained as it is partially imbedded in matrix, but the greatest width exposed is about 25 mm. The younger portion of the hook, excepting the inner or antisiphonal area, is ornamented with simple, rather oblique, and somewhat irregularly-placed ribs, which pass uninterruptedly over the periphery, where they are about 2 mm. apart; at irregular distances some of these are thicker than the rest and roughened and may originally have been produced into several small spines, but they are now too much abraded to state this with certainty; the later portion of the shell seems to have been ornamented with similar fine ribs, but at irregular intervals some of the ribs are greatly thickened on the outer portion of the lateral area and on the periphery of the whorl. The septa

[1] A. Redtenbacher, "Die Cephalopoden der Gosauschichten": Abh. d. k. k. geol. Reichsanst., Wien, Bd. v, 1873, p. 129, pl. xxx, fig. 10 (*Scaphites Sturi*).

[2] *Hamites reussianus* d'Orbigny, *Prod. de Paléont.*, vol. ii, 1850, p. 216. This species was placed by Pictet and Campiche in the genus *Anisoceras*; by Schlüter in the genus *Heteroceras*; and by Geinitz, Roemer, and Fritsch in the genus *Helicoceras*. For synonymy and references, see H. Woods, Quart. Journ. Geol. Soc., vol. lii, 1896, pp. 74, 75.

cannot be seen; possibly the whole of this fragment was occupied by the body-chamber.

The specimen greatly resembles the large example of *Heteroceras reussianum* (d'Orbigny) from the 'Scaphiten-Pläner' near Oerlinghausen, in the Teutoburger Wald, N.W. Germany, figured by Schlüter,[1] who states (*op. cit.*, p. 109) that this fossil is one of the most characteristic fossils of the 'Scaphiten-Pläner'. Although there are only obscure indications of the periodical spiny ribs such as are represented in Schlüter's figure, the fossil otherwise so closely resembles that figure, that it is here referred to the same species.

From England[2] this species has been recorded from the Chalk Rock (zone of *Holaster planus*) of Bedfordshire (Luton Railway Cutting,[3] and near Dunstable[4]); Hertfordshire (Hitchin;[5] Preston, near Hitchin;[6] Boxmoor, near Hemel Hempstead;[7] and Clothall, south-east of Hitchin[8]); Berkshire[9] (Cuckhamsley[10] and Basildon[11]); Oxfordshire (Aston Hill, near Aston Rowant;[12] and doubtfully from Chinnor Hill[13]); from the zone of *Holaster planus* in Buckinghamshire[14]; from the same zone at Dover[15]; and from the same horizon in Hampshire.[16]

EXPLANATION OF PLATE XXVII.

Pachydiscus farmeryi, G. C. Crick.

Fig. 1. Lateral aspect of the type-specimen; the finer peripheral ribs are shown on the right-hand side of the figure. Turonian, zone of *Holaster planus*: Boswell, near Louth, Lincolnshire. Original in the British Museum (Natural History), register No. C. 12,220. About four-fifths nat. size.

,, 2. Peripheral aspect of the same, showing the pairs of elongated nodes at intervals on the peripheral area; the finer transverse lines between succeeding pairs of nodes are visible in the upper part of the figure. About four-fifths nat. size.

Heteroceras reussianum (d'Orbigny).

,, 3. Small block exhibiting the terminal hook, and (at *a*) the impression of a small portion of the turreted part of a specimen. Turonian, zone of *Holaster planus*: North Ormsby, Lincolnshire. Original in the British Museum (Natural History), register No. C. 12,118. About two-thirds nat. size.

[1] C. Schlüter, *Palæontographica*, Bd. xxi, Lief. v, 1872, pl. xxxii, fig. 19.

[2] For list of foreign localities, see H. Woods, Quart. Journ. Geol. Soc., vol. lii (1896), p. 75.

[3] H. Woods, op. cit., p. 75. A. J. Jukes-Browne, *Cretaceous Rocks of Britain* (Mem. Geol. Surv.), vol. iii, *The Upper Chalk of England*, 1904, p. 228.

[4] H. Woods, op. cit., p. 75. A. J. Jukes-Browne, op. cit., p. 228.

[5] H. Woods, op. cit., p. 75.

[6] A. J. Jukes-Browne, op. cit., p. 228.

[7] *Ibid.*, p. 228. [8] *Ibid.*, p. 228. [9] *Ibid.*, p. 470.

[10] H. Woods, op. cit., p. 75.

[11] C. P. Chatwin & T. Withers, Proc. Geol. Assoc., vol. xx, pt. v, March, 1908, p. 407.

[12] A. J. Jukes-Browne & H. J. Osborne White, *Geology of the Country around Henley-on-Thames*, etc., 1908 (Mem. Geol. Surv. England and Wales, expl. of sheet 254), p. 54.

[13] A. J. Jukes-Browne, op. cit., p. 213.

[14] *Ibid.*, p. 470.

[15] A. W. Rowe, Proc. Geol. Assoc., vol. xvi, pt. vi, February, 1900, p. 366.

[16] A. J. Jukes-Browne, op. cit., p. 65.

Chalk Ammonoids from Lincolnshire.

III.—Some Ambulacral Structures in the Holectypoida.

By Herbert L. Hawkins, B.Sc., F.G.S.

THE phenomena of 'plate-crushing' in the course of the growth of the ambulacra of the regular Echinoids have for many years been utilized for purposes of classification of those forms, but the similar features which exist among some of the irregular types have not been studied in such detail as to render them systematically useful. It is with a view to showing that the structure of the ambulacra in one group of the Echinoidea Irregularia can be relied upon as an index of the relationships of the various genera, that this note has been written. It makes no pretence at completeness, as the material and time available have not been sufficient to allow of an exhaustive study. But the results of those observations that have been made seem to indicate that among the Holectypoida it should be possible, with the aid of zonal collecting, to trace genetic series among the various species, and perhaps to bridge the gulfs existing between the genera, by a study of their ambulacral plating.

That this method could be applied to the Holectypoida only seems certain. Among the Spatangoida the ambulacra are composed throughout of simple primary plates, varying greatly in shape and size, but not complicated by the development of demi-plates, except in the immediate vicinity of the peristome. The petaloid portions of the ambulacra in the Clypeastroida may exhibit the phenomena of 'plate-crushing', but I have only observed demi-plates in one specimen of a *Clypeaster* from the Miocene of Southern Europe. In any case, when the ambulacrum is traced beyond the limit of the petal, it is found to be composed of polygonal primary plates throughout its length.

In the Holectypoida, a group which is regarded as being the order of the Irregularia least removed from the regular type, the complexity of the ambulacral plating is often comparable with that in the simpler forms of the Diadematoida. Among the latter group, in the more primitive sub-order of the Diadematina, the ambulacrals are united in sets of three to form one compound plate, and a triple arrangement also obtains in the plates of the Holectypoida. But the arrangement of the component parts of a complete ambulacral in such a genus as *Conulus*, although in parts similar in appearance to that which is found in forms allied to *Arbacia*, is arrived at in a strikingly different manner. So regular is the order in which the plates become crushed into demi-plates that it is possible to regard the series of three which ultimately form a compound plate as being made up of three entirely different kinds of plate.

Before the region of crushing is reached there is no visible difference between the members of the simple row of primaries (see Fig. 2, *Pygaster*), but when the modification sets in, these plates succumb with surprising regularity, always in a definite order. It will be convenient for the purpose of this note to designate the individuals of the series of three plates by the letters *a*, *b*, *c* (see Fig. 1). These individual plates bear the following relation to one another: plate *a* will remain a primary throughout the entire ambulacrum, and will,

as it were, include the remnants of the others; plate *b* will retain its primary character later than plate *c*, and when both of these plates have become reduced, *b* will be constantly larger than *c*. The compound plate resulting from the maximum of crushing is composed, counting from its adapical suture to its adoral margin, of these three plates in the order *b*, *c*, *a*; *b* and *c* being let in to the adapical portion of *a*. This feature is explained by the diagram, Fig. 1. Irregularities occur at times in this sequence of events, more especially near the peristome, but in those cases of marked departure from the scheme that I have noticed there is always a tendency for the regular order to be resumed as soon as possible. The specimens that conform to this outline scheme are, however, very largely in excess of those which exhibit modifications, and I feel confident in regarding this as the typical ambulacral formation among the Holectypoida.

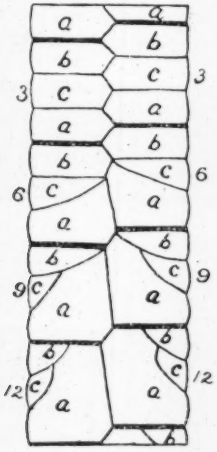


Fig. 1. Generalized diagram illustrating method of plate-crushing in the Holectypoida.

The feature of this 'plate-crushing' which seems to be most valuable for making a study of genetic affinities is that the point at which the demi-plates first appear varies in a constant series. In a suite of twenty specimens of *Conulus albogalerus*, the plate of set *c*, which first becomes modified, was always No. 9 (counting from the latest formed plate of set *a*), both in the five ambulacra of each individual and in the whole series of specimens. This fact seems to show that the position of the first 'crushing-point' may be relied upon as a specific criterion. An examination of several specimens of other species of *Conulus* confirms this belief. Further generalizations must, however, be postponed until a critical examination of certain forms has been undertaken, and the resulting diagram analysed.

The four genera here discussed are *Pygaster*, *Holectypus*, *Discoidea*, and *Conulus*. Species of all of these genera may be found in great abundance at various horizons in British Jurassic and Cretaceous rocks,

and so material for a genetic study of the forms merely awaits the accumulation of sufficient zonally-collected specimens.

Pygaster, Agass., first appears in the Upper Lias, and is possibly represented in the Middle Cretaceous by *P. truncatus*, Agass. The genus is, however, practically confined to the Jurassic Period.

Holectypus, Desor, originates in the Inferior Oolite, and continues into the lower part of the Upper Chalk (*H. serialis*).

Discoidea, Gray, is an essentially Cretaceous genus, commencing in the Lower Gault and disappearing at about the same horizon as does *Holectypus*.

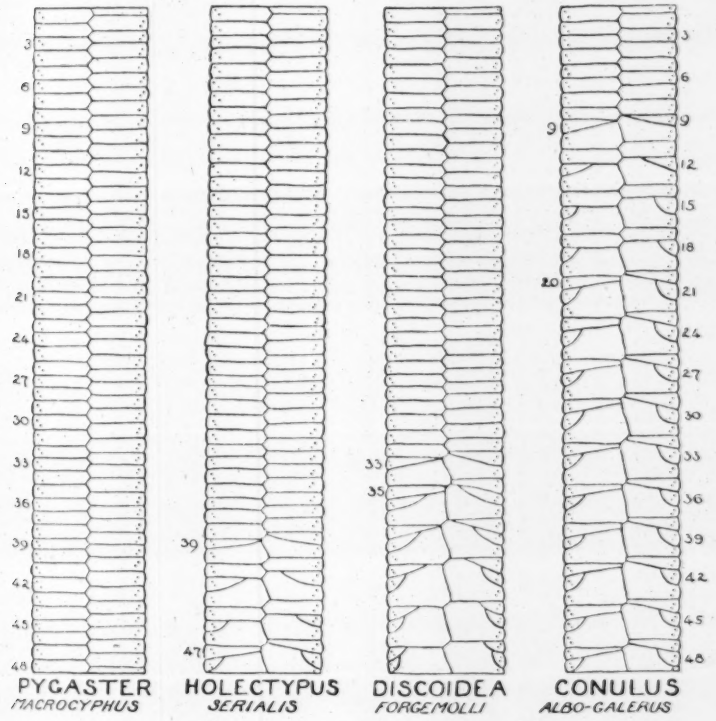


FIG. 2. Comparison of the plate-crushing in four Holectypoid genera.

Conulus, Leske, is another purely Cretaceous genus, first met with in the Upper Gault and persisting to the top of the Upper Chalk.

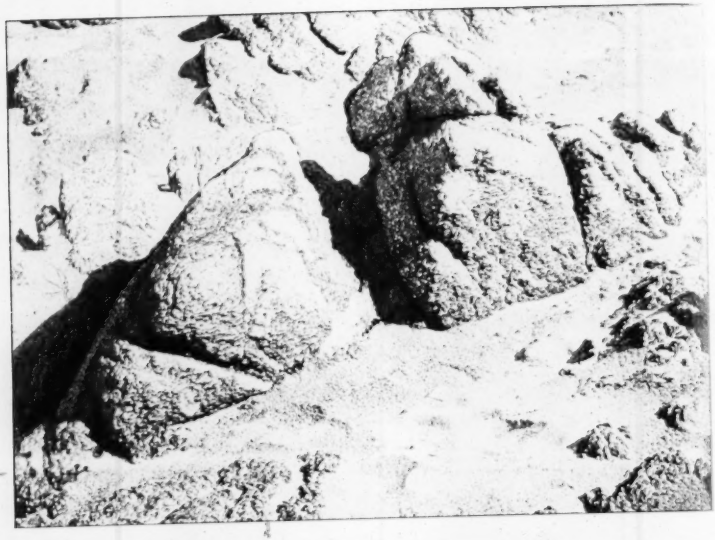
Considered in this order (that of their appearance in time), these four genera exhibit a fairly uniform series. *Pygaster*, with its periproct but slightly removed from the apex, and its well-developed jaws and external branchiæ, shows marked affinities with the Regulares; and *Conulus*, with a marginal periproct and probably no true jaws (when adult), is the most remote from the regular condition.

The four species I have chosen for the purpose of the diagram are, as far as I could obtain specimens, representative of the later specific developments in all four genera. The specimens utilized are all approximately adult.

Pygaster macrocyphus, Wright (the only traceable co-type of which is in the South Kensington Museum), is from the Kimmeridge Clay near Boulogne. Although the adapical regions of the test are considerably broken, enough of the ambulacra can be examined to show that considerably more than sixty consecutive ambulacral plates, counting from the apex, in each ray are simple primaries. Apparently the development of demi-plates does not commence until a region about half-way between the ambitus and the peristome. Examples of *P. semisulcatus* and *P. umbrella* which I have examined show at least an equal postponement of the 'crushing-point', but it is not often that specimens suitably preserved to show the plate sutures are met with among the Jurassic forms.

Holectypus serialis, Deshayes, from the Turonian of Algeria, is perhaps the latest member of the genus known. Two specimens in my collection show the plate sutures very clearly, although the diameter of the larger example is only 15 mm. The first indication of 'plate-crushing' occurs (of course, in set *c*) at plate 39, where this primary becomes wedge-shaped, reaching the median suture by a very narrow strip. Plate 42, the next of the *c* set, is definitely a demi-plate, and plates 41 and 43 meet round it along the median line. Whenever the plates of the *c* set are seen as the ambulacrum is traced towards the peristome, they are found to be demi-plates, whose extension towards the median suture becomes reduced the nearer they are to the mouth. Plate 47 is the first member of set *b* to show a cuneiform shape, and by the time plate 56 is reached this set also is represented by demi-plates, and the median ambulacral suture is entirely formed by the large primaries of set *a*. In *H. depressus* from the Lower Oolites, the crushing of the plates of set *c* is postponed beyond plate 50, and that of the plates of set *b* yet further from the apical system. Thus in earlier Jurassic times this genus would appear to have been similar to *Pygaster* in the structure of its ambulacra, but to have developed in the course of time a far more complex condition than was ever reached by the latter genus.

Discoidea Forgemolli, Coquand, from the ? Senonian of Algeria, exhibits the phenomena of 'plate-crushing' in a degree advanced from that in *Holectypus*. Plates of set *c* begin to appear compressed and wedge-shaped at number 33, and the reduction in size of the plates of set *b* is accelerated to such an extent that while plate 36 (set *c*) is but hardly separated from the median suture, plate 35 is already cuneiform. In a *D. cylindrica* from the Lower Chalk the first indication of crushing in set *c* appears at plate 39, and in set *b* at plate 41. So that in this earlier form the proportionate rate of crushing of the two sets of plates is similar to that in *D. Forgemolli*, but the point at which it commences is postponed by six plates. It will be noticed that in the case of *D. cylindrica* the 'crushing-point' is identical with that in *Holectypus serialis* from a newer horizon. There is thus some overlapping in this feature among the various genera, but in the fully specialized members



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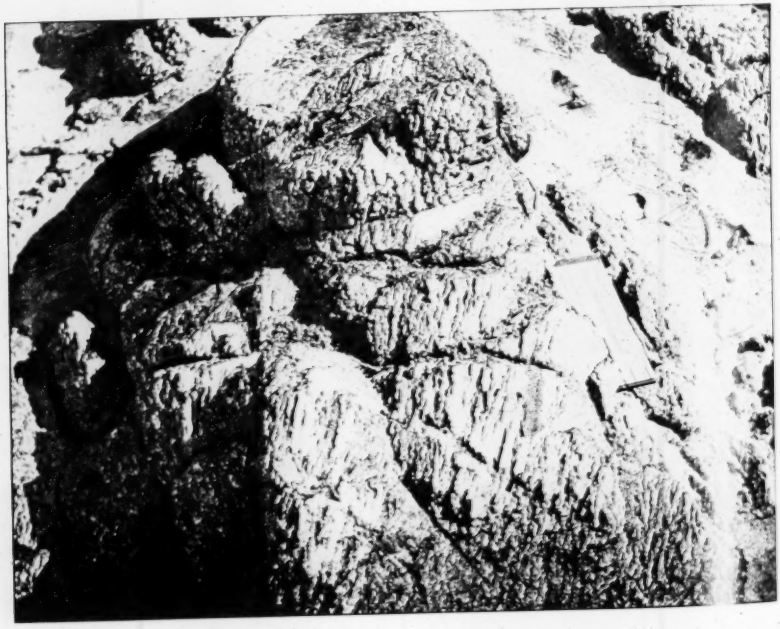

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T. O. Bosworth, photo.

Wind-eroded Rocks on the Coast of Mull.

of each genus the distinction holds good. The very fact of the overlapping would tend to confirm the supposition that this 'plate-crushing' is of genetic value, and that parallel development takes place among the several genera.

In the case of *Conulus albogalerus*, Leske, from the Upper Senonian, the crushing is markedly earlier in its origin. So much so that, whereas in *Holectypus* and *Discoidea* the ambulacra on the adapical surface of the test seem almost entirely composed of primaries, in *Conulus* the great bulk of each ambulacrum is built of crushed plates. The first indication of crushing in set *c* appears at plate 9, and in set *b* at plate 20. But while in set *c* the plates become small demi-plates inserted in the outer angles of the others by the time plate 15 is reached, in set *b* the primary character lingers on until plate 42. Thus the greater part of the median ambulacral suture is made up of the edges of plates belonging to sets *a* and *b*. This perpetuation of the primary plates in set *b* would appear to be a special feature developed in the course of evolution of the genus, for in *C. subrotundus* from the Cenomanian, while the plates of set *c* begin to diminish in size at number 12, and those of set *b* at number 20, the latter set of plates becomes definitely separate from the median suture at number 53.

There seems, therefore, to have been in the history of the development of the Holectypoida a tendency to introduce 'plate-crushing' in the ambulacra to an increasing extent. As this feature may very likely be connected with two other noticeable characters of the progressive development (increase in the height of the adapical surface of the test and narrowing of the ambulacra), it should serve as a useful index to the genetic relationships of the various genera and species. As I have not sufficient material to investigate the ambulacral structures of the other genera of the order, nor the opportunity of collecting sufficient numbers of specimens for working out specific relations within the various genera, I have thought that the above indication of the possibility for important evidence on this branch of evolution might perhaps induce others, more favourably situated in these respects, to continue and amplify the study.

IV.—Wind Erosion on the Coast of Mull.

By T. O. Bosworth, B.A., B.Sc., F.G.S.[1]

(PLATES XXVIII AND XXIX.)

THE Ross of Mull is a comparatively low-lying peninsula exposed to the storms and swept by gales from the Atlantic. On these rocky shores are occasional stretches of sand which frequently have been driven inland, forming dunes and patches of blown sand at intervals around the coast. Sometimes the sand is forced up the cliffs and deposited more than 100 feet above the sea, and there are places in the centre of the peninsula where the blown shell-material is quite a noticeable constituent in the soil.

In one instance, the peculiarities of which are here to be described,

[1] With permission of the Director of the Geological Survey.

the dune formation is accompanied by considerable rock erosion. On the north coast 3½ miles north-west of Bunessan, and half a mile west of the bay called Camas Tuath, is a smaller bay marked on the 6-inch map as Traigh na Margaidh. It is one-sixth of a mile wide at the mouth and reaches thence one-fifth of a mile inland. In this inlet, which is bounded by granite cliffs, there is a wide stretch of white sand, which, followed inland, becomes a mantle of blown sand spreading over and banked up against the granite rocks. This sand is decidedly more worn than that on the beach, and the sorting of the grains is more complete. Magnetite grains are abundant in it; and from one sample 5 per cent. by weight was easily extracted with a magnet.

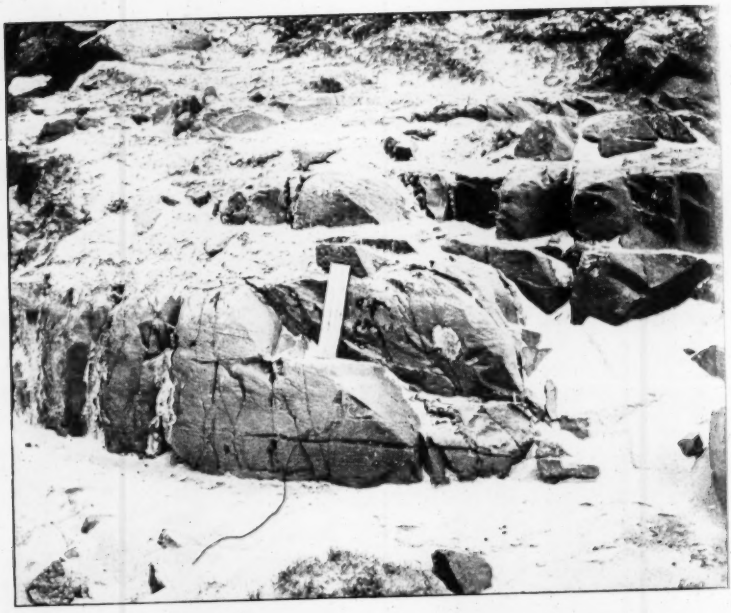
The granite is coarsely crystalline and of homogeneous texture, without any parallelism of minerals or any sign of shearing. The joint planes here are vertical with directions 45° W. of N. and 30° E. of N.

The wearing of the rocks on the sides of the bay and on the hummocky masses more or less buried in the sand indicate within the inlet a prevalent N.N.W. wind, straight up the bay and up the 'slack' which is its landward continuation. The crests of the elongated mounds of sand which have formed on the lee side of the hummocks also have this trend, and the crests of the ripples are at right angles to it.

The hummocks are elongated in the direction about 15° W. of N. They are often undercut and worn to a somewhat conical shape with the point more or less sharpened and facing the wind. (See Pl. XXVIII, Fig. 1.) On these windward ends smooth hollows have been formed in the felspar, and deep narrow-mouthed pits where mica has been, while the quartz stands out as tiny smooth knobs sometimes mounted on diminutive undercut stalks of pink felspar, like a minute collar stud. (See Pl. XXVIII, Fig. 2.)

The surfaces of the rocks and hummocks are highly polished and curiously corrugated, being worn into regular ridges and furrows. (See Pl. XXIX, Fig. 3.) From the windward ends of the hummocks these radiate as from a focus, but on the flat surfaces they are more strictly parallel, trending N.N.W. The ridges vary considerably in dimensions; commonly they are about a quarter of an inch apart, and the furrows say one-tenth of an inch deep, but in some cases the ridges are an inch apart and the furrows one-third of an inch deep, and in others there are as many as ten ridges to the inch. Sometimes there are major and minor corrugations. The furrows are formed in felspar, but each ridge begins abruptly at its windward end with a quartz crystal worn into a smooth polished convex cap and often almost worn away. The remainder of the ridge consists mainly of pink felspar sheltered from destruction by the quartz, and, unless some more quartz is encountered, the ridge dies out in the course of an inch or two. Both quartz and felspar are so highly polished that they have a sub-pearly lustre.

Loose boulders of granite, that probably have not lain long in place, are corrugated like the rocks, and a loose block of basaltic rock from a neighbouring dyke was seen to be fluted in a somewhat similar way, a relatively large crystal of ferromagnesian mineral forming the



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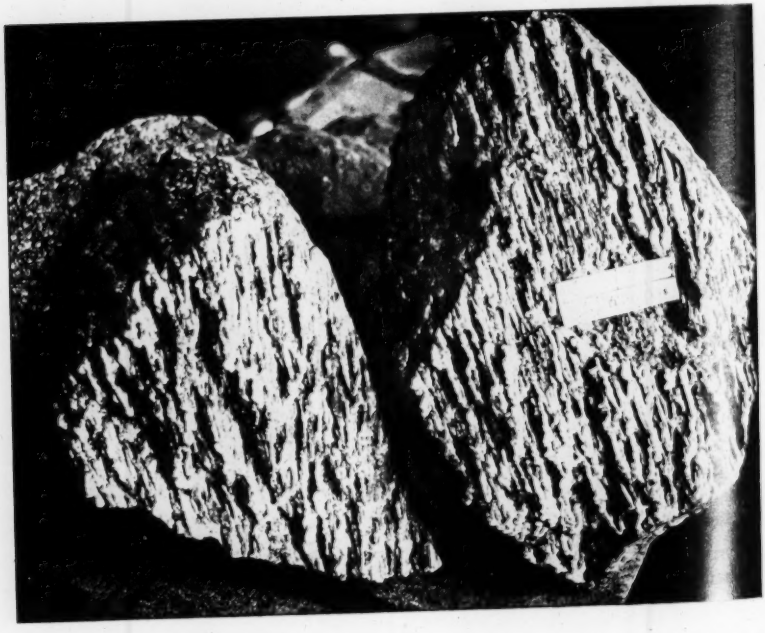

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T. O. Bosworth, photo.

Wind-eroded Rocks on the Coast of Mull.

windward end of each little ridge. A few wind-cut pebbles also lay upon the sand.

Such surfaces as these, which thus at every point bear record of the exact direction of the eroding sand drift, can only be formed in places where the direction of the wind is constant. Probably this condition is here almost perfectly realized; the direction of the air currents being determined by the shape of the bay, so that changes in the wind outside affect only their intensity and not their direction. The bearings quoted here are from measurements on one particular hummock; they vary somewhat from place to place in the bay, and in the arm, which branches off to the east, the dunes and corrugations are from west to east.

Higher up among the rocks at the south end of the bay is a slightly inclined 9 foot sheet of mica trap which projects out from the rock side forming a bench whose foot is reached by the banked-up sand. The front of this sill is nearly vertical and is divided up by the joints into some four or five layers of rectangular blocks. The blown sand strikes obliquely against this wall of rock, and at one place every block has had its front top windward corner eroded away (Pl. XXIX, Fig. 4). In some cases several small facets have been cut, meeting in fairly sharp edges. A few of the facets are furrowed, each minute furrow beginning in a ferromagnesian mineral, but generally the corner surfaces are instead almost covered with small pittings, and are conspicuous on account of their peculiar colour. Normal weathering gives the rock a red-brown rough surface, but these corner surfaces appear from a slight distance of a dark-purple plum colour, to which a little polish has added the appearance of bloom. The purple effect is due to the steel black colour in the pittings. It is removed to some extent by acid yielding a solution containing iron. Possibly it is due to a thin film of fine magnetite dust imparted by the magnetite grains in the blown sand.

Thus wind-blown sand is here ever at work on the rocks in advance of the waves, lengthening the bay at its landward end, and so playing some small part in the coast erosion.

EXPLANATION OF PLATES XXVIII AND XXIX.

Plate XXVIII.

Fig. 1. Two of the small hummocks, conical in front, with points towards left-hand lower corner of picture. Both are about 18 inches high.

,, 2. Front of a rock facing the wind. Lower middle part of picture shows projecting knobs of quartz; middle of picture is a more horizontal surface with corrugations; upper middle portion is a vertical surface facing wind, and studded with knobs of quartz. Scale, 6 inches.

Plate XXIX.

,, 3. Two specimens of corrugated rock surface. Left-hand specimen was a surface which met wind obliquely; right-hand specimen an horizontal surface. Scale, 4 centimetres.

,, 4. The sill of mica trap which is met obliquely by the wind. Top front windward corner of each block worn away. Scale, 1 foot.

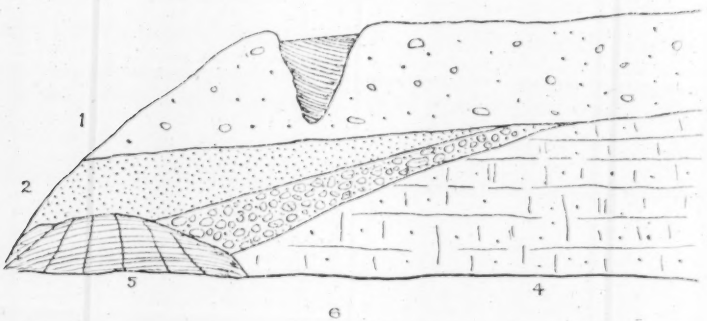
V.—A Buried Valley at North Sea Landing, Flamborough.

By T. Sheppard, F.G.S.

DURING the last few weeks East Yorkshire seems to have been severely dealt with by wind and hail and flood, and in common with the rest of the area the cliffs have suffered. Geologists, however, are able to profit where others lose, and as a result of disasters can obtain useful information in reference to the structure of a district. Perhaps one of the most interesting exposures that has recently been made occurs at the south extremity of North Sea Landing, Flamborough, where a large amount of cliff has recently slid down on the beach.

There have been two landslides at this particular point; the upper one, which occurs at the top of the cliff at a height of about 125 feet above the sea, has carried away the footpath along the cliff edge, and in other ways has made things disagreeable. Beyond exposing a clean face of purple Boulder-clay, however, it has revealed nothing of particular geological interest.

The second landslide occurs almost immediately below, in the part of the cliff which rises to a height of about 35 feet direct from the beach. There is still a tongue of soft Boulder-clay, which forms a talus, and covers up part of the section, as shown in the diagram. This second landslide has exposed a glacial valley which apparently at one time had an outlet to the sea at this point. As one faces the land, the section occurs immediately to the right of the concrete slope up which the fishing cobbles are drawn.



Section of lower part of cliff at south extremity of North Sea Landing, Flamborough. 1, Basement Boulder-clay, 15 feet; 2, angular chalk 'grut', 6 feet; 3, chalk rubble, 6 feet; 4, chalk with flints, 20 feet; 5, talus; 6, beach.

The upper part consists of about 15 feet of dark lead-coloured Boulder-clay, very different in appearance from that on the higher slopes. This bed evidently represents the 'basement' clay; it certainly is precisely similar to the deposit which occurs immediately above the chalk 'wash' at Sewerby. This Boulder-clay entirely covers the solid chalk at North Sea Landing, as well as the deposits resting in the pre-Glacial hollow. The Chalk itself, which is to the right of the section, is about 20 feet in exposed thickness, and contains

thin beds of flint, and the echinoderm *Holaster planus*. Where the Chalk has been cut into by the valley the upper portion is considerably disintegrated and discoloured. This rubble is about 6 feet in thickness in the lower part, and thins out towards the right; and where the Boulder-clay rests directly upon the Chalk it is missing altogether, having probably been planed off by the moving ice.

To the left of the section there is a wedge-shaped mass of fine, clean, angular chalk 'grut', which is about 6 feet thick at the left of the section and gradually tapers off towards the right. This 'grut' is evidently of very early date, as it contains a fairly large proportion of small well-rounded quartzite pebbles, such as occurred at the top of the Wolds in pre-Glacial times.[1] The chalk 'grut' at North Sea Landing is precisely similar to the deposit at Sewerby described by Mr. G. W. Lamplugh[2]; in fact, in general appearance it is precisely similar to that on the buried cliff, though unfortunately there is no beach material exposed at North Sea Landing, nor is this to be expected. The section just exposed at North Sea Landing therefore seems to indicate the position of a pre-Glacial outlet on Flamborough Headland, which has not previously been described. This had been partly filled in by chalk 'wash' in early Glacial times; the whole valley had subsequently been blocked by drift during the Great Ice Age, and had since remained hidden until exposed by the recent landslip.

VI.—The Development of Uralite and other Secondary Amphiboles: a brief History of Research in that subject.

By Albert Wilmore, D.Sc. (Lond.), F.G.S.

IN the year 1831 the famous mineralogist and chemist, Gustav Rose, described a mineral which he had observed in his travels in the Urals the previous year.[3] He pointed out that he had found in the greenstones of the Urals crystals with the cleavages and the prism angle of hornblende, but with the external form of augite. The porphyritic crystals of these greenstones are sometimes hornblende, sometimes augite.

In a greenstone near Bogoslowsk, 437 versts north of Ekaterinberg, there are large dark crystals of hornblende with perfect cleavage. They have also the crystal form of hornblende, showing typical symmetrical six-sided sections with two angles of 124½° when the section is transverse to the ortho-axis, and angles of 156½° when the section is parallel to that axis. There is often a core of augite, and in the larger crystals this core is surrounded by a comparatively narrow zone of dark hornblende. In the smaller crystals the augite core is very small and sometimes it is quite wanting. To these crystals of hornblende, so clearly derived from augite by some alteration, he gave the name of *Uralite*.

[1] See *The Naturalist* for 1904, pp. 54–6.
[2] Quart. Journ. Geol. Soc., August, 1891, pp. 384–431.
[3] Pogg. Ann., 1831, Bd. xxii.

In giving reasons for the grouping of hornblendes and augites into one family, he called attention to the fact that when hornblende is fused in a platinum or graphite crucible, crystals result which have the form of augite. Augite crystals are found in slags, but never hornblende crystals. The melting-point of hornblende is lower than that of augite. In 1833 Rose gave further localities for uralite.[1]

Meanwhile Professor Glocker had cast doubts on the secondary origin of this uralite; he had suggested that it might be due to hornblende enclosing, in crystallizing, a core of augite, or that an original crystal of augite had had a zonary growth of hornblende formed round it (Schwegger's *Jahrbuch*, Bd. v, p. 373). Rose replied to these suggestions, and insisted on the unity of the augite and hornblende families. He also gave further localities for secondary hornblende.[2] Rose then discussed the question whether hornblende and augite should be considered as two dimorphous substances, and he showed that though their chemical composition is very similar it is not identical. Later on he suggested the possibility of the change from augite to hornblende being due to the higher oxidation of the ferrous oxide of the augite.

These observations of G. Rose are the first systematic descriptions of a secondary mineral, and are the precursors of much important work in connexion with changes in the minerals of rocks which could only be carried out after the application of the microscope to petrological study.

The subject does not seem to have attracted much attention until the era of microscopic petrology had dawned, but from 1876 onwards one finds a continuous series of important papers dealing more or less directly with uralite.

In 1876 J. A. Phillips called attention to the "pseudomorphic origin" of many of the minerals of the greenstones of Western Cornwall.[3] Some of the rocks are gabbros or dolerites, in which the original constituent minerals are occasionally, to a great extent, unchanged, but are sometimes almost entirely represented by "pseudomorphic forms".

In the same year S. Allport described the rocks surrounding the Lands End mass of granite.[4] Allport made an interesting observation which shows that he regarded the process as almost entirely one of paramorphism. "The alteration that has taken place appears to be the result of internal rather than of external action; in other words, it must have been caused by a more or less complete decomposition and re-arrangement of mineral substances in situ, and not to any great extent by the introduction of new material from without."

This seems to have been one of the first suggestions, that the production of hornblende by change from augite is one of simple paramorphism, an idea which was afterwards developed more fully, especially by G. H. Williams. As will be seen later, it does not now seem feasible to regard the change as of so simple a nature, at any

[1] Pogg. Ann., Bd. xxvii, pp. 97–106.
[2] Ibid., 1834, Bd. xxxi, pp. 609–22. Dana gives the date as 1831.
[3] Quart. Journ. Geol. Soc., 1876, vol. xxxii, pp. 155–78.
[4] Ibid., pp. 407–27.

rate in the majority of cases. Rose's original suggestion, though only touching one aspect of the possible chemical changes, was nearer the truth.

In 1880 von John described Flysch gabbros from Bosnia ("Über Kryst. Gest. Bosniens": Jahrb. der k.k., etc., Vienna, 1880), and he stated that the kind of secondary hornblende produced depends upon the composition of the original pyroxene. Brown hornblende results from the alteration of dark diallage, but green hornblende from the alteration of green diallage. The secondary brown hornblende is very strongly dichroic, but the hornblende derived from the light-green diallage is fibrous and almost colourless. The hornblende passes by further change into chlorites.

Cohen (*Sammlung von Mikrophot. von Mineralien u. Gest.*, Stuttgart, 1884) illustrated the development of uralite in his pl. xlvi, figs. 1–4. Fig. 1 shows the beginning of uralitization in the periphery of a crystal, and is taken from a micro-section of the so-called uralite-porphyry from Predazzo in the Tyrol. Fig. 2 shows the beginning of uralitization in the central part of a crystal, and is from a 'proterobase' from near Audlan in the Vosges. Fig. 3 shows complete uralitization; section parallel to the vertical axis, and is again from the uralite-porphyry of the Tyrol. Fig. 4 shows complete uralitization; section nearly at right angles to the vertical axis. It is from the so-called uralite-porphyry of Miask in the Urals. The form is augite, the cleavage that of hornblende.

An important work is Lehmann's study of the crystalline schists of Saxony, etc.[1] In ch. xiii, p. 191, which deals with gabbros and amphibole rocks (Amphibolgesteine), he mentioned a series of secondary minerals, among which are amphibole, saussurite, magnesia-mica, etc. He described the change from pyroxene to amphibole as one of paramorphism. Later, p. 197, he described amphiboles of secondary origin, which are sometimes like smaragdite, sometimes like actinolite. The amphiboles and other secondary minerals are due in part to pressure. An important observation is that the formation of magnetite often accompanies that of amphibole derived from hypersthenes rich in iron.

We now come to the very important series of contributions made by Professor Judd during the years 1885–90. Though not the earliest of the series it may be well to take first the Presidential Address to the Geological Society of London in 1887.[2] This address deals with the morphology, physiology, chorology, and ætiology of minerals. In the section treating of the physiology of minerals Professor Judd pointed out the importance of recognizing the different *structure-planes* of crystals. The most obvious of these are the *cleavage-planes*. These, however, are not the only latent structure-planes in crystals. Brewster, Reusch, and Pfaff had shown long ago that when crystals are subjected to pressure in certain directions their molecules appear to glide over one another along certain definite planes within the crystal, and if we examine optically a crystal which has been treated

[1] *Untersuchungen über die Entstehung der Altkrystallinischen Schiefergesteine*, Bonn, 1884.

[2] Quart. Journ. Geol. Soc., vol. xliii, p. 68 et seq.

in this manner it is actually found to exhibit a series of twin-lamellæ arranged parallel to the so-called *gliding-planes*.

There is still a third and even more subtle set of structure-planes in crystals, those, namely, for which the name of *solution-planes* has been proposed.

In the section dealing with the 'ætiology' of minerals (the causes by which the existing forms, capabilities, and position of minerals and rocks have been determined) Professor Judd compared the change from unstable monoclinic sulphur—by a pressure of 5000 atmospheres—to the stable rhombic form, and that of yellow mercuric iodide, by simply rubbing, into the stable red tetragonal form, with the "paramorphic change of pyroxene into hornblende, which is so frequently exemplified in the earth's crust".

In the next paper to be noticed he explained his now well-known theory of schillerization, and showed the connexion between this process and the planes of discontinuity in crystals.[1] This paper is of importance in connexion with uralitization, as it deals to some extent with augite, diallage, and the amphiboles, and the changes set up in the pyroxenes.

The difference between minerals found at great depths and the same minerals found near the surface is sometimes original—due to pressure and slow growth—sometimes secondary, such as the bands of fluid enclosures, the avanturine structure, and the chatoyant phenomena.

The same phenomena, but more closely connected with the subject of this paper, were further elucidated in a paper by Professor Judd in 1890.[2] In that paper he reviewed the work of Mügge on the diopsides of Ala, of Phillips and Teall on the Whin Sill augites, and showed that augites in the Tertiary basalts of Ardnamurchan present the same features, viz. lamellar twinning parallel to the basal plane (001) and not parallel to the orthopinacoid (100). According to the work of Mügge this may have been caused by pressure. The lamellar twinning or parting of diallage, parallel to the orthopinacoid (100), is due to solution acting along the solution-planes.

There is one other paper by Professor Judd which should be included in this important series.[3] This paper deals with a pyroxene-felspar rock at Oodegaarden, near Bamle, in Norway. This rock has been converted into hornblende-scapolite rock. MM. Fouqué and Michel-Lévy had shown that by fusion (with a trace of sodium fluoride) and slow cooling this hornblende-scapolite rock is, in turn, converted into a pyroxene-felspar rock.

The change of felspar into scapolite may be followed step by step. The solvent which attacked the felspar crystals along their solution-planes, and which acted under statical pressure, contained sodium

[1] "On the relation between the Solution-planes of Crystals and those of Secondary Twinning, etc.: a contribution to the Theory of Schillerisation": Min. Mag., 1887, vol. vii, pp. 81–93.

[2] "On the relation between the Gliding-planes and the Solution-planes of Augite": Min. Mag., 1890, vol. ix, pp. 192–6.

[3] "On the process by which a Plagioclase Felspar is converted into a Scapolite": Min. Mag., 1889, vol. viii, pp. 186–98.

chloride. The felspars of this Oodegaarden rock evidently became saturated along their solution-planes with sodium chloride in solution, and the effect of the internal stresses in the rock masses was to "bring about those chemical reactions by which the felspar-molecules were broken up and their materials united with the sodium chloride to form scapolite".

The pyroxene has undergone a precisely parallel series of changes. The original pyroxene was very nearly colourless, probably an enstatite. It was converted into a schillerized 'bronzite' by enclosures parallel to a pinacoid. This pale-coloured bronzite is, in places, found to be acquiring the characteristic colour, pleochroism, and absorption of brown hornblende.

The last stage in the change of the Oodegaarden pyroxene is seen in certain crystals which, around their edges and in certain patches in the middle, exhibit the full pleochroism, the absorption, and the characteristic cleavage of hornblende. This is often accompanied by 'granulation' of the broad plates of the original pyroxene. The original rock appears to have a perfectly granitic structure, but the derived hornblende-scapolite rock has a granulitic structure.

The effects produced are the results—

(1) of chemical action resulting from statical pressure (schillerization);
(2) of changes induced by the internal stresses set up in a rock during its deformation in the act of flowing (dynamo-metamorphism).

Professor Judd described the change from pyroxenes to hornblende as a 'paramorphic' one, but that from felspar to scapolite as a 'pseudomorphic' one.

Two important papers of a different type by Professor Judd may now be noticed. The first of these is his well-known paper on the Peridotites of Scotland.[1] In this paper he gave a classification of pyroxenes with 'Schiller' varieties, which is here reproduced.

	Unaltered forms.	*'Schiller' varieties.*	*More altered forms.*
Enstatites (*Rhombic*)	Enstatite proper	Diaclastite?	
	Proto-bronzite	Bronzite	Tale?
	Proto-hypersthene	Hypersthene	
	Amblystegite	Hypersthene	Bastite
Augites (*Monoclinic*)	Diopsides	Diallage and	Green diallage
	Augite proper	Pseudo-	and
	Hedenbergite	hypersthene	Smaragdite

An interesting alteration series is given on p. 381 of this paper—

Augite, diallage, green diallage → Smaragdite, Actinolite and similar hornblendes.

On p. 386 he distinguished 'weathering' changes which produce kaolinization, uralitization, serpentinization from the changes which produce schillerization. The latter is deep-seated, the others are not deep-seated.

The next paper of Professor Judd deals with the Tertiary Gabbros in Western Scotland and Ireland.[2] In it he emphasized most strongly

[1] "On the Tertiary and older Peridotites of Scotland": Quart. Journ. Geol. Soc., 1885, vol. xli, pp. 354–418, pls. x–xiii.
[2] Quart. Journ. Geol. Soc., vol. xlii, p. 49 et seq.

the unstable nature of the minerals of the basic rocks. The felspars are found changed into saussurite, the augites into hornblende, the olivine into serpentine and magnetite. Still further changes may have taken place by which the rock is converted into hornblende-schist or gneiss.

Almost contemporary with this important series of papers were several contributions by Dr. Teall. Of these the first was an oft-quoted paper on the Metamorphism of a Dolerite Dyke into a Hornblende-schist.[1] At Scourie in Sutherlandshire occurs a dyke of hornblende-schist, which is clearly the result of metamorphism of a dolerite. In this paper Dr. Teall made a number of very important observations relative to such questions as the various stages in the development of the secondary hornblende and the production of foliation.

Of the two minerals, augite and hornblende, the former appears to be the stable form at high temperatures, the latter at low temperatures, "so that any condition tending to facilitate molecular readjustment must necessarily tend to facilitate the change from augite to hornblende. The enormous pressures brought into operation in the process of mountain-making may not unreasonably be supposed to supply such conditions."

Analyses of the dolerite of the hornblende-schist are given, but apparently the only safe conclusions from percentages which are very similar in the two cases are—

(1) That the change has almost been one of simple paramorphism.
(2) That there may have been some conversion of ferrous into ferric oxide.

Dolerite	FeO	14·71	Hornblende-schist	FeO	11·71
	Fe_2O_3	2·47		Fe_2O_3	4·35

In a paper dealing with some minerals from the Lizard,[2] Dr. Teall described a (probably) secondary hornblende, a very pale variety occurring in a gabbro-schist at Pen Voose. This was analysed by Mr. J. H. Player.

SiO_2	48·8	CaO	12·2
Al_2O_3	10·6	MgO	18·6
Fe_2O_3	1·7	Ignition loss	1·8
FeO	4·7		

On this analysis Dr. Teall remarks: "If this hornblende be secondary, then its composition does not bear out the view that secondary hornblende is derived from pyroxene by a paramorphic change."

In 1885 Dr. Hatch[3] described gabbros passing into amphibolites, the alteration series being—

Normal gabbro, hornblende gabbro, amphibolite, epidote rock.

Another alteration series is suggested, as follows:—

Normal gabbro, uralite gabbro, actinolite or nephrite-schist, serpentine.

[1] Quart. Journ. Geol. Soc., 1885, vol. xli, pp. 133–45.
[2] "Notes on some Minerals from the Lizard": Min. Mag., 1888, vol. viii, pp. 116–20.
[3] "Über den Gabbro aus der Wildschnonau in Tyrol," etc.: T.M.P.M., 1885, Bd. vii, pp. 75–87.

Pressure is clearly seen to have been effective in converting the diallage into hornblende. The crystals of the former were bent, stretched, and partly destroyed. Hornblende is developed along the cracks in patches and round the edges. A large quantity of magnetite has been developed as the result of the change from diallage to hornblende. The extent to which secondary hornblende has been produced is a measure of the schistose character developed in the rock, until, with complete change of the original diallage to hornblende, an amphibolite or nephrite-schist is produced.

The next contribution to be noticed is that of Harker in his Sedgwick Prize Essay of 1888.[1] In ch. vi, on Diabase Sills, etc., it is pointed out that the augite has fringing growths of hornblende, these also traversing it in strings and sometimes extending into the decomposed felspar. This secondary amphibole is always in crystalline relation with the augite from which or in which it grows.

The pseudomorphic hornblende is for the most part truly secondary in the ordinary sense of the word. In one or two examples, on the other hand, there are appearances which suggest that the amphibolization may have begun before the final solidification of the rock, e.g. when a grain of augite is seen partly pseudomorphosed by hornblende which is in crystalline continuity with hornblende moulding the grain.

We now come to some of the more important papers from the pens of the American petrographers. First among these may be taken a paper by G. H. Williams.[2] This a very suggestive paper. It is pointed out that pyroxene and hornblende are two different crystallographic forms of essentially the same molecule. Some experimental work is reviewed. In 1824 Mitscherlich and Berthier melted *tremolite* at the Sèvres pottery works and found that augite resulted on slowly cooling. G. Rose in 1831 had performed a similar experiment with actinolite from the Zillerthal. Fouqué and Michel-Lévy have since corroborated. A second paper by Williams in 1890[3] contains important suggestions upon the whole question of secondary amphiboles. This memoir is intended as a contribution to the study of dynamic or regional metamorphism.

Of the various types of alteration discussed, uralitization occupies a prominent place. It is made to include the derivation of any hornblende, fibrous or compact, from pyroxene. In discussing this process it is pointed out that though it has often been referred to as one of paramorphism it is more than that in many cases. Forchhammer, Rose, and Svedmark have shown that when augite changes to fibrous hornblende, magnetite and often calcite are separated out between the needles.

Williams pointed out that Harrington, of Montreal, had analysed three stages in the alteration from pyroxene to a secondary fibrous hornblende, and found that during the change there was a loss of lime

[1] *Bala Volcanic Series of Caernarvonshire*, Cambridge University Press, 1888.

[2] "On the Paramorphosis of Pyroxene to Hornblende in Rocks": Amer. Journ. Sci., 1884, vol. xxviii, No. 16, pp. 259–68.

[3] "The Greenstone Schist Areas of the Menominee and Marquette Districts, Michigan": Bull. U.S.G.S., 1890, No. 62.

and a gain of magnesia. (This change is, however, far from constant. See, e.g., Teall on the Scourie Dyke.)

It was further pointed out that the schistose structure of the rocks is largely due to the production of fibrous hornblende. This secondary fibrous hornblende does not remain in the area formerly occupied by the pyroxene; amphibole needles are even found along the cleavage cracks of the felspars. Some other points from this important memoir are—

(1) Brown hornblende passes into green hornblende by the reduction of its iron from the ferric to the ferrous state; afterwards loss of iron produces fibrous and less coloured hornblende.

(2) Very often there is a double hornblende zone round a pyroxene core: first (inner) brown and more compact hornblende, then green and more fibrous hornblende.

Another important United States monograph is that of F. D. Chester.[1] He distinguished between tremolite and fibrous green hornblende in his remarks on rocks at Iron Hill. Tremolite is evidently regarded as colourless or nearly so. Fibrous green hornblende surrounds hypersthene cores, and tremolite fibres are developed irregularly within the core. Much magnetite is set free as the result of the change, which Chester described as a paramorphic one.

It is pointed out that 'uralite' is used in an ambiguous way—

(1) To indicate a substance with the external form of augite, but the cleavage and optical properties of hornblende.

(2) Fibrous hornblende is loosely described as uralite.

The three papers by W. S. Bayley on the Basic Massive Rocks of the Lake Superior Region necessarily contain several references to uralite and uralitization.[2] The first of these papers gives an interesting history of the classification of the gabbros from the time of Hauy. The third article contains an account of the different structure-planes noticeable in some of the augites. Diallage cleavages are accentuated by dark decomposition products, the most abundant of which are tiny irregular black and brown dots. These are scattered everywhere throughout the pyroxenes, but are accumulated most thickly in the neighbourhood of the cleavage lines. Peculiar platy inclusions characteristic of gabbro-diallage are seen in some of the pyroxenes. These are often arranged in straight lines crossing the parting-planes. They are frequently so crowded that the line of inclusions appears as a dark bar crossing the diallage at various inclinations to the cleavage.

In 1888 A. C. Lawson, of the Canadian Survey, made some contributions to our knowledge of the subject.[3] In a chapter on the Petrography of the Keewatin Series he pointed out that the pyroxene of rocks of the gabbro type is more resistant to 'paramorphic change' than the augite of the diabases. Shreds of fibrous hornblende or actinolite derived from augite are observed to have been developed within the substance of the fresh plagioclase, and along its line of

[1] "The Gabbros and Associated Rocks in Delaware": Bull. U.S.G.S., 1890, No. 59.

[2] *Amer. Journ. Sci.*, 1893, vol. i, pp. 433, 587, 688.

[3] Report on the Geology of the Rainy Lake Region: Geol. and Nat. Hist. Surv. of Canada, Montreal, 1888.

contact with the augite. In another part he noticed that secondary hornblende, chlorite, and epidote have been developed very extensively along cleavages and cracks of the fresh plagioclase.

The recent Survey memoir dealing with the north-west of Scotland[1] contains numerous references to the subject. It is shown that hornblende is sometimes compact and gives no evidence of secondary origin, but on the other hand *much* of the hornblende is evidently secondary after pyroxene. Some of the hornblende-felspar rocks of the Lewisian gneiss show hornblende with pyroxene cores (p. 62). The basic dykes and sills also show much secondary hornblende. The famous Scourie Dyke (*vide ante*) is quoted as an example.

The presence of pyroxene cores in hornblende, the occurrence of needles of hornblende in the felspars (p. 93), the extension of the hornblende individuals parallel to the direction of shearing are observations similar to others already noted. Granulation of pyroxene is also noticed.

The larger textbooks of mineralogy and petrology have, of course, devoted some space to a consideration of this subject. Zirkel, in his *Lehrbuch der Petrographie*,[2] discusses "Secundäre Amphibole" at some length. There is a good general summary of the chief observations followed by a discussion of the nature of the chemical changes involved. One observation is worth reproduction. Schwerdt (*Zeit. Geol. Ges.*, 1886, p. 225) records a case of Chiness diorite in which uralitization has commenced in the middle of the augite crystals so that green fibrous hornblende is seen to be surrounded by an envelope of compact augite.

In the chemical discussion it is emphasized that the passage from pyroxene to amphibole is more than a mere paramorphism; it is a change of augite substance into hornblende substance. The analysis of the Ottawa uralite by Harrington is given (*vide ante*). This shows a loss of Ca O of 9 per cent. and a gain of Mg O of 3½ per cent. There is an increase of both ferrous and ferric oxides. There is also an analysis of a uralite derived from the pyroxene of a gabbro from Zwartekoppies (Dahms). This shows *a gain* of Ca O of 6 per cent., a loss of Mg O of 6 per cent., and a gain of Fe O of 3 per cent. These results are obviously quite contradictory, but it is pointed out that the first case concerns a basic rock rich in lime (24·44 per cent.), while the second deals with a rock poor in lime and rich in magnesia and iron oxides.

The deposit of needles and microliths of hornblende in the felspars of many rocks — the so-called erratic (gewanderte) hornblende — receives fairly full treatment, and there is a series of references.

Quite recently MM. L. Dupare & T. H. Hornung[3] have made a most interesting contribution to the literature of this subject. Their paper is entitled "Sur une novelle théorie de l'ouralitisation". They describe the alteration noticed in a fine series of rocks collected in the Northern Urals. These rocks are very 'fresh' and are made up of

[1] "The Geological Structure of the North-West Highlands of Scotland": Mem. Geol. Surv. Great Britain, 1907.

[2] 1893, vol. i, p. 316 et seq.

[3] C.R. Acad. Sci. Paris, vol. cxxxix.

basic labradorite, pyroxene, green hornblende, and magnetite. All the forms and stages of uralitization may be seen, and it is possible to separate completely specimens of the almost unaltered pyroxene and the almost fully uralitized mineral. The results of the mean of two concordant analyses of these extreme cases are given.

	Pyroxene, D. 3·358.	Amphibole, D. 3·213.
SiO_2	50·91	43·34
Al_2O_3	2·64	12·60
Fe_2O_3	—	10·44
FeO	10·07	7·92
MnO	Traces	Traces
CaO	23·33	13·06
MgO	12·30	12·60
K_2O	—	0·02
Na_2O	—	1·90
Loss on heating	—	0·22
	100·25	102·10

The authors claim that these analyses dispose of the idea of a dimorphous molecule, and that the remarkable freshness of the rocks preclude any idea of hydrochemical processes. The examination of a great number of sections shows that the manner of the uralitization depends upon the permeability of the pyroxene. If the latter are impermeable the change is only peripheral; if, however, there exists in the pyroxenes "une ligne de pénétration ou un accident quelconque dans la structure" the uralitization is internal. This is interpreted as showing that the pyroxenes after crystallization have been acted upon by the still liquid magma. The primordial magma has first of all allowed the crystallization of pyroxene and basic felspars. Before the complete consolidation of the rock the bath has been modified in composition by the action of mineralizing agents. The bath, thus modified, has reacted upon the pyroxenes, enriching them in alumina and in iron and depriving them of some lime.

It appears probable that the explanation of Duparc & Hornung applies only to certain cases, otherwise one would expect uralitized pyroxenes to be as common in recent rocks as in more ancient igneous rocks, whereas it has over and over again been pointed out that uralitization is rarely found in the more recent basic rocks. The suggestion at once occurs that uralitization is a general term which has been used to describe more than one type of mineral alteration. These types may be tentatively summarized as follows:—

(1) The alteration of diallage to uralite by the action of hot liquids under pressure and at high temperature and containing various dissolved salts, these liquids having penetrated the various planes of discontinuity in the crystals. In this way brown or green more or less compact hornblende may be produced according to the nature of the original pyroxene and the composition of the penetrating fluid.

(2) The alteration of compact secondary hornblende to fibrous actinolite or tremolite, by the gradual leaching out under conditions of moderately high pressure and temperature of more or less of the iron. This process seems to take place in the upper part of the zone of katamorphism, while the former process seems to be characteristic of the lower part of that zone.

These two processes cannot, of course, be sharply separated. There is every possible gradation and combination of the two. The second process may have proceeded to some extent, and then the former may be superimposed, with the result that, in some cases, there has clearly been a passage from pyroxene through fibrous hornblende to compact brown or green hornblende.

(3) There may be magmatic resorption and corrosion of pyroxenes with the result that amphiboles of various kinds, usually aluminous hornblendes, are formed on the periphery, and along and near the planes of penetration, and in the extreme case there may be complete magmatic reconstruction of the pyroxene into hornblende. When this extreme result has been reached it will be clearly impossible to determine the 'secondary' character of the hornblende unless there is a series of partially resorbed crystals to act as a guide. It is, of course, possible to describe such a hornblende as original.

This will probably take place in the zone of anamorphism, and in the upper part of that zone; while the converse change may be looked for in the lower part of that zone, and amphiboles of specific gravity 3 to 3·3 may be converted into pyroxenes of specific gravity 3·2 *to* 3·5 approximately.

Note I, on Melting-points of Pyroxenes and Amphibole.—The following results have been published by the authors named:—

	Cusack.	*Doelter.*	*Brun.*
Augite	1187°	1085°	1230°
	1199°	1200°	
Hornblende	1187°	1065°	1060°
	1200°	1155°	1070°

Cusack: vide *Roy. Ir. Acad.*, vol. iv, pp. 399–413.

Doelter: *Tscherm. Min. Petr. Mitth.*, vols. xx–xxii; *Physikalisch-Chemische Mineralogie*, pp. 99–100.

Brun: *Arch. Sci. phys. et nat.*, Geneva, vol. xiii, pp. 352–75.

Vogt, Day, and others have obtained much higher melting-points for the simple pyroxene diopside, up to 1375°.

Allen, Wright, and Clement (*Amer. Journ. Sci.*, vol. xxii, pp. 385–438) give 1521° as the melting-point of the high temperature stable form of the $Mg\,SiO_3$. Instead of simply regarding this simple metasilicate as dimorphous they regard it as tetramorphous, as follows:—

Monoclinic pyroxene; rhombic pyroxene (enstatite);
Monoclinic amphibole; and rhombic amphibole.

The pyroxenes are stable at high temperatures, the monoclinic form being the most stable; the amphiboles are low temperature minerals, and probably change into stable pyroxenes at high temperatures. Hence we can understand the formation of pyroxene from amphibole as recorded by Lacroix in the lavas of Auvergne. (See also Harker, *The Natural History of Igneous Rocks*, Methuen, 1909, pp. 155–8.)

Note II, the Angle Relations of Augite and Hornblende.—Take the average prism angle of augite as $87\frac{1}{2}°$ and that of hornblende as $124\frac{1}{2}°$. Now take half of each of these angles. The following important relation is now evident:—

$\tan 62\frac{1}{4}°$ is approximately 1·90,
$\tan 43\frac{3}{4}°$ is approximately ·95.

That is, the tangent of half the prism angle of hornblende is twice the tangent of half the prism angle of augite.

REVIEWS.

I.—Geological Survey Memoirs on Water Supply.

1. The Water Supply of Hampshire (including the Isle of Wight), with Records of Sinkings and Borings. By William Whitaker, B.A., F.R.S., with contributions by H. R. Mill, LL.D., W. Matthews, M.Inst.C.E., and J. C. Thresh, M.D. 8vo; pp. v, 252, with two maps. Price 5*s*.

IN our volume for 1909 (p. 180) we drew attention to Mr. Whitaker's *Water Supply of Kent*, and now he has prepared an elaborate account of the springs and streams, the wells and borings of Hampshire. In both works are embodied the result of labours extending over many years, and including experience gained by field work during the geological survey of the respective counties.

The deepest boring in Hampshire, made during the years 1838–51 at Southampton, was carried to a depth of 1317 feet through Tertiary strata without reaching the base of the Chalk. This is not surprising, as the estimated thickness of that formation in the Isle of Wight is more than 1700 feet. The oldest formation known in the county is the Wealden, above which there occur a continuous series from the Lower Greensand to the Chalk, and the most complete series of Eocene and Oligocene strata known in any county, the Thanet Beds only being absent. The chief water-bearing strata are, in order of importance, the Chalk, Lower Greensand, Upper Greensand, and Bagshot Series.

An interesting and instructive map of the valleys of the Test and Itchen is contributed by Mr. Matthews, the object being to indicate the position of eighty-six wells, and the contour-lines in the surface of the underground water in the Chalk. The data on the map show (with two exceptions) the water-level in February, 1899. It is noted that the surface-contours of the land, although not coinciding with the water-contours, have in general a distinct relation to them; nevertheless, the water-contours "will obviously be moving with the seasonal and other variations in the water-levels, and those represented on the map can only be taken as showing average and approximate levels". Thus gaugings made between 1884 and 1899 prove that seasonal "variations range from about 5 feet in wells in the low ground, to as much as 63 feet in the case of wells sunk at the higher elevations".

Mr. Whitaker remarks that Hampshire is noted for the largest spring supply in the kingdom, that of the Portsmouth Water Company, which is derived from chalk water; the springs at Havant and Bedhampton yielding from 11 to 21 million gallons a day.

Many intermittent streams or bournes, swallow-holes, and other phenomena are described; and some particulars relating to the rivers are given.

The records of strata passed through in wells and borings, and analyses of water (many of which have been contributed by Dr. Thresh)

occupy the main portion of the work. Sundry mineral waters are noted, mostly chalybeate, those of Shanklin and Chale being the best known. It is stated that Bembridge is supplied from a shallow well in the Bembridge Limestone, known as "Centurion's or St. Arian's Well". The former name has been regarded by some as a misnomer, recorded by the Ordnance Survey instead of St. Urian's (here given as St. Arian's). A bibliography contains lists of publications of the Geological Survey, the Local Government Board, and of other works that bear on the water supply of Hampshire. Particulars relating to the rainfall, accompanied by a map, are contributed by Dr. Mill.

2. The Water Supply of Oxfordshire, with Records of Sinkings and Borings. By R. H. Tiddeman, M.A., F.G.S., with contributions by H. R. Mill, LL.D. 8vo; pp. iv, 108, with map. Price 2*s.* 3*d.*

THIS work has been appropriately prepared by Mr. Tiddeman, who studied geology under John Phillips at Oxford, and after many years service on the geological survey retired to the neighbourhood of his Alma Mater.

The strata which come to the surface in the county include the entire Jurassic series, the Cretaceous from the Shotover Sands and Lower Greensand to the Upper Chalk, together with Reading Beds, London Clay, Pleistocene, and Recent deposits. The principal water-bearing strata are the Inferior and Great Oolite Series, Corallian, Lower and Upper Greensand, Chalk, and Valley Gravel. The deepest boring, that at Burford Signet, made during the years 1875–7, was carried to the base of the New Red Sandstone Series (depth 1184 feet), and then into Coal-measures (226 feet), the total depth being 1410 feet. The object was apparently to reach Coal-measures, but why no further proceedings were taken when those strata were reached has not been made known. As a rule the waters obtained in Oxfordshire beneath the Oxford Clay and Kellaways Beds have proved to be saline, notably at Oxford itself, at Upper Arncot, Bampton, and Kidlington. Where not covered by Oxford Clay good supplies have, as a rule, been obtained from the Great Oolite beneath the Forest Marble and Cornbrash, and from the Inferior Oolite, as at Bicester. Saline waters have been encountered also in the Lower Greensand beneath the Gault at Shillingford. Mr. W. W. Fisher, who has contributed records of many analyses, remarks that in the waters below the Oxford Clay the amount of alkaline salts is usually so great that the supplies are unfit for domestic or industrial purposes. He believes that the alkalies are normal constituents of the strata, and that they have become concentrated in situations where little or no circulation has been possible. Long-continued pumping ought in these circumstances to improve the supplies.

Dr. Mill contributes a map and explanatory notes on the rainfall. There is also a bibliography, drawn up on similar lines to that noticed in the Hampshire Memoir.

II.—Geology in the Field. The Jubilee Volume of the Geologists' Association (1858–1908). Edited by H. W. Monckton and R. S. Herries. Part III. pp. 433–660, with 6 plates. London: Edward Stanford, 1910. Price 5*s.* net.

IN the March Number of the Geological Magazine we called attention to the issue of the second part of this Jubilee Volume. The third part has now been received, and it contains nine articles.

"The Weald" is dealt with by Mr. Herries, who first briefly discusses the great anticline, the successive stages of elevation, the river-systems, and the denudation. The main characters of the different formations from the Purbeck Beds to the Upper Greensand are then described, and some account is given of Pleistocene and Recent deposits. Finally the author sums up the knowledge acquired by the various deep borings.

"Northamptonshire (including contiguous parts of Rutland and Warwickshire)" is the title of the second essay, contributed by Mr. Beeby Thompson, who likewise refers to the local deep borings, and thus deals briefly with Archæan and other formations not exposed at the surface. Those which are to be seen in the field include the members of the Jurassic Series from the Lower Lias to the Oxford Clay, together with sundry Pleistocene and Recent deposits. In the higher stages of the Lower Lias the author recognizes in upward succession the following Ammonite-zones: *Jamesoni*, *Pettos* (described by him in 1899), *Ibex*, *Henleyi*, and *Capricornus*. The Upper Lias is divided into "eight subsidiary zones, or sets of beds", and is covered conformably by the representatives of the Inferior Oolite. A zealous collector of fossils, Mr. Thompson has added largely to our knowledge of the palæontology of the different strata which occur in Northamptonshire.

"Lincolnshire" is described by Mr. Jukes-Browne, who took a considerable share in the geological survey of the county. Strata of Triassic age are first described, and a record of the Boultham boring, for the water supply of Lincoln, is given on the authority of Mr. Henry Preston. A good supply of water is stated to have been obtained from the Keuper Sandstones at the depth of 1563 feet. This supply, though abundant, proved to be saline; but we are informed by Mr. Preston that a really good supply for Lincoln has since been obtained from the Bunter near Retford. The author gives particulars of the several divisions of the Lias, of the Inferior Oolite Series with its basal ironstone worked at Greetwell, of the higher Jurassic strata up to the Kimeridge Clay, and of the Cretaceous Series. After describing the Glacial Drifts he expresses his dissent from the view of Mr. Harmer that the Honington and Lincoln gaps were formed during the Glacial epoch by the overflow of a lake caused by the advance of an ice-sheet.

"Nottinghamshire" is described by Professor J. W. Carr, who deals with strata from the Millstone Grit to the Lower Lias, a series marked by great unconformity at the base of the Permian. The author remarks that "Where the junction of the Permian and Trias is seen there appears to be a perfectly conformable passage from the one to the other, but the Triassic strata rest in succession on all the

divisions of the Permian, and to the west of Nottingham the Trias overlaps the Permian, and lies directly upon the Coal-measures". These conditions suggest that some movements were in progress during Triassic times leading to local erosion of the Permian. Some account is given of the superficial deposits and the bone-caves of Cresswell Crags.

"The Lower Carboniferous Rocks of Derbyshire" are the subject of an essay by Mr. Arnold Bemrose, who briefly refers to previous excursions to the district. The Carboniferous Limestone and its zones of fossils, first investigated in detail by Mr. C. B. Wedd, the toadstones, the dolomitized limestone, the caverns, and the lead-mines, all receive attention. The so-called Yoredale Rocks are described under the heading of "Limestone Shales" ("Upper Limestone Shales" would have been better); the Millstone Grit is described, and there is a brief account of the "Sands and Fire Clays in the Mountain Limestone", which are stated to be pre-Glacial. Glacial Drift, cavern deposits with Pliocene and Pleistocene mammalia, Tufa, and warm springs are also described.

"Staffordshire" is treated by Dr. Wheelton Hind, who first deals with the intrusive rocks of Rowley Regis and other places, and with the Silurian. The Carboniferous Limestone Series is next described, and then the Pendleside Series, which after all is a portion of the Limestone Series. Special attention is given to the life-zones in these groups, as well as in the Millstone Grit Series and Coal measures. The Triassic, Pleistocene, and Recent deposits are briefly described.

"East Yorkshire" is the subject of an article by Mr. Herries, who has to deal with a long list of formations between the Lower Lias and Upper Chalk. With the aid of many illustrative sections and his personal knowledge of the strata and their fossils, an excellent summary is given of the main features of this attractive area, and particularly of the coast-sections between Redcar and Bridlington.

"The Lake District and Neighbourhood—Lower Palæozoic Times" and "The Lake District and Neighbourhood—Upper Palæozoic and Neozoic Times" are the titles of two essays contributed by Dr. J. E. Marr. He deals with many formations from the Skiddaw Slates, which represent Arenig and possibly Tremadoc and earlier beds, and the Borrowdale Series grouped as Llandeilo, to the Lower Lias of the area west of Carlisle, and the Glacial and more recent deposits. The various igneous rocks are also described. It is not certain that Rhætic beds are absent, but their presence has not been proved owing to the covering of Glacial drifts. The leading fossils and zonal divisions in the Carboniferous and older Palæozoic rocks are duly pointed out. The author observes that a "great hiatus occurs above the Carboniferous rocks, for the highest Coal-measures, the whole of the Permo-Carboniferous rocks, and the lowest Permian strata as developed elsewhere, are absent". Here a good deal depends on what may be included in "Permo-Carboniferous". The complex physical changes, the main faults and flexures that were produced after Lower Palæozoic times, and again after Carboniferous times, and their influence on the present physical features, are concisely described.

(Part IV will be reviewed next month.)

III.—Report on the Mines and Mineral Resources of Natal (other than Coal). By F. H. Hatch, Ph.D., M.I.C.E. Published by order of the Natal Government. London: Richard Clay and Sons, 1910.

A CLEAR statement as to the actual mineral wealth of a country and the present stage of its development is seldom afforded us, for where so many interests are at stake an unbiassed account is generally withheld. When, therefore, we have the opinion of an expert of such wide experience as Dr. Hatch we ought to be truly grateful. It is not, however, our province to discuss the commercial attitude of this report, nor is it for us to say whether it is politic to make known the results achieved by individual and pioneer undertaking.

Though not optimistic Dr. Hatch is certainly not wholly pessimistic as to the future mining industry of Natal. What the colony has done up till 1908 is forcibly shown by the statistical tables on p. 125, in which, by the way, the author luxuriates in a ton of 2440 lb.

Geologists will be chiefly interested in the author's succinct outline of the general geology of Natal and Zululand, though some will not unhesitatingly accept his correlation of the Table Mountain Sandstone of Natal with the Waterberg Sandstone of the Transvaal. Useful, too, are the notices of the occurrence and distribution of the metalliferous deposits in the colony. With the exception of iron, nickel, and molybdenum the metals appear to be chiefly confined to the complex of rocks older than the Table Mountain Sandstone and included by Dr. Hatch in the Swaziland System. The Witwatersrand formation is not recognized, and the auriferous conglomerates ('bankets') are considered to be contemporaneous with the Swaziland Beds, and therefore to be older than the Banket formation of the Rand. It is disappointing to learn that the iron-ores nowhere appear to be of any great thickness, and that limestones suitable for employment as a flux are of rather rare occurrence in Natal.

To further the mining industry of the colony Dr. Hatch considers a geological survey, such as was commenced in 1898 and precipitately abandoned in 1905, to be an important factor.

IV.—Geology. By Professor J. W. Gregory, F.R.S. 8vo; pp. 140, with 41 text-figures (including a map). London: J. M. Dent and Sons, Ltd. No date. Price 1*s.* net.

THE little work before us is one of a series of Scientific Primers, which are intended to give a simple and general account of the present state of knowledge in various branches of science. At the outset we must find fault with the publishers for not inserting a date either on title-page or in preface—a very serious omission in a work of which the aim is to be 'up to date'.

In an introductory textbook it is always difficult to know how far the knowledge of the reader can be taken for granted in dealing with the facts and phenomena. In this respect Professor Gregory has succeeded as well as possible, considering that he gives special attention to the materials of which the earth is made, and he rightly

refers to Sir W. Tilden's primer of Chemistry for an explanation of chemical processes. Commencing with a short account of the early history of the earth, he passes on to the study of rocks, dividing them into Primary and Secondary, the former including all the Igneous rocks and the latter all the Aqueous or Stratified rocks. This is not in accordance with the general usage of the terms, and is to be deprecated; but the descriptions of the rocks and of their method of formation are clear and instructive. More generally interesting is the section on Physical Geology, in which modern agents and the arrangement of rocks in the field are dealt with. Here we note that the author applies the term erosion to the widening of a valley, and corrosion to the cutting of a gorge. The term erosion is by most geologists employed for all kinds of denudation. Under Historical Geology the author gives a brief account of fossils and of the geological systems, and introduces a short notice of Gondwanaland, which is illustrated by a map of the world in the Upper Carboniferous era.

The primer should prove useful to general readers as well as to students and science-teachers, and is well calculated to stimulate further inquiry.

V.—The Miner's Guide. By F. P. Mennell, F.G.S. London: Gerrards, 1909. 4*s*. net.

PRESENT-DAY civilization imposes a heavy toll on the mineral resources of the globe. There is no metal that is not turned to some use. There is no quarter of the globe, not excepting the Polar regions, to which the discovery of mineral wealth does not instantly attract public attention, and there is no nation in the possession of more real and prospective mineral wealth than that which lies within our own empire. Yet how few are able to distinguish one mineral from another, or have any idea as to the rocks in which mineral deposits are likely to occur! Elaborate treatises, and textbooks beyond count, are on the market; but most of these are written for the initiated and are not serviceable to the untrained, by whom the want of a clearly written and practical guide has long been felt.

In *The Miner's Guide* Mr. Mennell has, we think, successfully supplied this deficiency in our scientific literature. How rocks and minerals are formed, how they occur, by what means they can be distinguished, and how their value may be ascertained, are made clear to all who possess an elementary knowledge of chemistry. Quite fittingly, the author illustrates his text with examples taken from his wide knowledge of the mineral deposits of South Africa, Rhodesia in particular. Other countries are referred to, but all too briefly. Coal and oil are summarily dismissed, and we are erroneously informed that the "well-known coalfields" of Ireland are of Silurian age.

The practical nature of Mr. Mennell's clever outline is its chief attraction, but we think that a book dealing with a subject of such general interest possesses an educational value, especially as in this instance the information is obtained at first hand, and the writer has the ability to present his subject in a clear and concise manner.

VI.—Index to Desor's Synopsis des Echinides Fossiles. By F. A. Bather, M.A., D.Sc., F.R.S. Avec une note sur les dates de publication du *Synopsis* par Jules Lambert. Published by the Author, Fabo, Marryat Road, Wimbledon, England, May, 1910. Price to subscribers, 7*s*.

THIS Index, to the preparation of which the Geological Magazine drew attention some time ago, has now been published and should prove of great use to every worker on Echinoids, whether fossil or recent, and to those who, without claiming to be specialists, frequently have occasion to look up a name. Reference is made particularly easy by the fact that the Index is arranged in two parts, the first under the names of species in alphabetical order, the second under the names of the genera, the name of each genus being followed by a list of the specific names that are in any portion of the book associated with it. The value of such an Index will be more apparent when it is remembered that the *Synopsis* was issued in parts and that several of the pages were cancelled, additions being made later on. Also there were several series of Addenda, and various names occur either in the plates, or in the tables, or in foot-notes, to which reference is by no means easy; in fact, many of them almost entirely escape observation.

Systematists have long been puzzled by the fact that this original *Synopsis* was issued in separate parts, and that owing to the destruction of the original wrappers they were quite unable to determine the dates of the various names that occur in it. This task has now been accomplished for them by Mr. Jules Lambert, who, together with the late P. de Loriol, spent many years in trying to obtain the necessary details. The whole of the results are summarized in a collation of a supposed bibliographically complete copy.

Dr. Bather deserves the gratitude of his fellow-workers for undertaking this laborious task, and we may express a hope that their gratitude will be shown by a speedy sale of the work.

VII.—Brief Notices.

1. Hanging Valleys.—In the Bulletin of the American Geographical Society (1909) Professor D. W. Johnson deals with two questions involved in the problem of glacial erosion: (1) Are hanging tributary valleys a reliable indication of glacial erosion of the main valley? (2) May not hanging tributary valleys result from glacial widening of the main valley, instead of from glacial deepening? In the paper the author discusses the origin of hanging valleys, and deals with a number of glaciated valleys in Europe.

2. The Relation of Geology to Topography.—Professors D. W. Johnson & F. E. Matthes contribute a chapter with this heading to Breed & Hosmer's *Principles and Practice of Surveying* (New York). After pointing out the value of a knowledge of geology to the topographer, as giving him "some understanding of the conditions under which the surface was formed", the writers point out by a series of diagrams the differences between accurately and inaccurately mapped mountain areas. They show also how correct contouring of

a district brings out the detail of glaciation, alluvial fans, volcanic features, dome mountains, and general physiography or topographical geology.

3. Oil Shales of Canada and Scotland.—Dr. R. W. Ells has just issued in the Department of Mines, Canada (Ottawa, 1910), a long report on the oil-shale industry of Scotland, New Brunswick, and Nova Scotia. This report treats of the geology, history, statistics, analyses, cost of plant, commercial value, and many other points useful to those interested.

4. "Elephants' or Buffaloes' Wallows" the work of Earthworms.—*The South African Journal of Science* is the organ of the South African Association for the Advancement of Science, and is a monthly record of science and economics. In the part for February, 1910, J. A. H. Armstrong writes on the geology and mineralogy of Natal, and he refers incidentally to those curious pits or hollows known as "elephants' or buffaloes' wallows". Setting aside the older theories as to their origin, (1) wallow holes, (2) native iron-ore digging, (3) ancient gold-diggings, (4) percolating waters, Mr. Armstrong thinks they are the work of earth-worms alone. He gives a number of strong arguments in favour of his views, and seems to have made a singular and thoughtful observation.

5. Mount Etna.—On March 23 this volcano burst forth into activity after a series of minor earthquakes, the outbreak being the most violent since the great eruption of 1892. Streams of lava issued from five craters, and united to form a great stream that moved at the rate of more than 60 feet an hour, and was estimated to be 12 feet high and more than 1500 feet in width. Quantities of scoriæ were also ejected mainly from the highest crater. The lava-stream subsequently divided, portions extending to the Galvagna district, south of Mont San Leo, approaching Borello and also Nicolosi. Ultimately more than fourteen craters were in eruption. On the evening of March 26 the volcanic activity ceased, but a renewed eruption, of less intensity, was reported on March 28, and on April 9 it was announced that Etna was again in violent eruption.

6. The New Zealand Geological Survey in Bulletin No. 7 (New Series), 1909, has issued a report on "The Geology of the Queenstown Subdivision, Western Otago Division", by Mr. James Park. This is evidently an attractive district, as Queenstown "is picturesquely situated on the raised lake-beaches and great moraine overlooking Queenstown Bay and Frankton Arm. Its scenic marvels and sunny salubrious climate have made it the chief centre of the tourist traffic in the South Island". The geological formations consist mostly of mica-schists grouped as Palæozoic, with strata grouped as Lower Miocene (Oamaru Series), Pleistocene Boulder-clays, moraines, and terrace-gravels, and Recent alluvial deposits. Evidence is given of overthrusting in the older schists, whereby wedges of Miocene strata have been included along certain thrust-planes, a feature of remarkable interest. Proof is also presented to show "that the Lake Wakatipu region was covered by a continuous ice-sheet of vast depth in the Pleistocene period—a continental ice-sheet that reached to the sea, and probably covered the greater part of the South Island".

Gold-bearing lodes occur in the schists, but alluvial mining has been by far the most productive source of the metal. Igneous rocks do not occur in situ, but many pebbles and boulders occur in the fluvio-glacial drifts, and these are described. The work is fully illustrated by maps, sections, and pictorial views.

7. Board of Agriculture.—We are glad to note that Dr. J. J. H. Teall, F.R.S., Director of the Geological Survey and Museum, is a member of the Committee recently appointed by Earl Carrington to advise the Board on all scientific questions bearing directly on the improvement of agriculture. A carefully surveyed geological map on the scale of 6 inches to a mile is the best foundation for the more detailed study of soils, and indeed for appraising the value of an estate. As we noted in reference to Soil Surveys in the United States (Geol. Mag., 1908, p. 277), the so-called 'soil-maps' are geological maps representing the subsoils or geological formations (whether Solid or Drift), there is no attempt to map the constantly varying soils, but information relating to their depth and character is given in many places on the maps from data obtained by means of spade or hand-borer.

8. "Sketches of Gaspé" is the title of a little book by Mr. John M. Clarke (Albany, 1908), in which the author gives an interesting account of the scenery, geology, and of many other matters relating to "that vast peninsula of Eastern Quebec which lies between the mouth of the St. Lawrence River and the Bay of Chaleur, facing the waters of the Gulf of St. Lawrence".

9. Geological and Petrographical Researches in the North Urals.—"Recherches géologiques et petrographiques sur l'Oural du Nord, le bassin de la haute Wichéra," by Professor Louis Duparc, aided by Professor F. Pearce and Miss Marguerite Tikanowitch (Mém. Soc. Phys. et Hist. Nat. de Genève, xxxvi, 1909, pp. 33–210). In this work the authors describe the eruptive rocks (diabases) which are generally intrusive in the metamorphic or pre-Devonian rocks, and these 'crystalline schists' are also described in detail. Middle and Lower Devonian, Carboniferous, and Quaternary deposits complete the list of formations represented. Brief descriptions only are given of them, attention being devoted to the geological structure and physical features, and to the mode of occurrence and origin of the iron-ores. The memoir is fully illustrated by pictorial views, plans, geological sections, and microscopic rock-sections.

10. The Waters of the Great Lakes of North America are described by Mr. R. B. Dole (Journ. New England Water Works Assoc., xxiii, 1909). Samples were collected monthly for a year from each lake, and a tabular statement is now given of the mineral analyses. Around Lake Superior igneous and crystalline rocks predominate, and the water contains on the average sixty parts per million of solids; whereas Lakes Erie and Ontario contain about two and a half times the amount of solid constituents, due mainly to material derived from calcareous sedimentary formations. The lakes are almost invariably softer than their affluents, as might be expected from the effects of direct rainfall. The suspended matter is practically all deposited by sedimentation.

11. Sand-Barytes from Kharga, Egypt (Proc. U.S. Nat. Museum, xxxviii, 1910).—Mr. Joseph E. Pogue describes and illustrates sundry forms of Sand-Barytes. The figures recall to mind examples of selenite charged with sand-grains, the occurrence of which in the Oldhaven Beds has been noted by Mr. Whitaker. As the author remarks, calcite, gypsum, and barite are distinguished above all other minerals by the large quantities of sand which they can enclose upon crystallization. The specimens he describes were probably formed by the deposition from solution of barium sulphate in the interstices of loose sand during the consolidation of the Nubian Sandstone.

12. Sections from Deptford and Catford to Plumstead.—Mr. R. H. Chandler has contributed very useful detailed accounts of sections exposed by the two new sewers: Deptford to Plumstead and Catford to Plumstead (Trans. West Kent Nat. Hist. Soc. for 1908–9, 1910). The particulars are systematically recorded and illustrated by map and sections. Strata from the Chalk to London Clay with superficial deposits were encountered; and in the low-level sewer from Deptford, during construction, more than 3,000,000 gallons of water were pumped from the Chalk in the course of twenty-four hours. Remains of Mammoth and *Bos primigenius* were obtained from the Valley Drift at Greenwich.

13. Fossils in the Algonkian of Scandinavia.—In the Stockholm "Geologiska Förhandlingar", vol. xxxi, 1909, p. 725, Dr. A. E. Törnebohm announces the discovery of fossils in a crystalline limestone at the northern end of the Great Arfven Lake, west of Lake Wener, Sweden, as well as in the Berikalk of Gudbrandsdal, Norway. The appearances in question have been known for some time, but have only recently been determined by Professor Rothpletz as calcareous algæ. Beside these Dr. Törnebohm has found other structures which appear to be of organic origin. The whole microscopic look of the rocks is that of certain younger limestones known to be composed of fragments of organisms.

14. Victorian Fossils.—Mr. Frederick Chapman continues his energetic attempt to describe the new or little known Victorian fossils in the National Museum, Melbourne, in the "Proceedings of the Royal Society of Victoria". His tenth contribution contains worms and Crustacea, and includes Silurian *Trachyderma* of two species, two interesting forms of *Turrilepas* from the same formation, a *Ceratiocaris*, and a *Xiphidiocaris*. Mr. Chapman invariably draws his own figures, and if his efforts in that direction are a little crude, we may rest assured that his detail is extremely accurate.

15. Cretaceous Plants.—Messrs. Stopes & Kershaw describe in the *Annals of Botany*, April, 1910, some pine leaves from the Cretaceous of Japan, and discuss their relationship with other Cretaceous species, and with the living forms of America. Incidentally the authors diagnose the genus *Prepinus*, Jeffrey, 1908, as that author apparently forgot to do so. In a second paper Dr. Stopes describes the internal anatomy of a leaf of *Nilssonia orientalis*, Heer, also from Japan. The result of the examination of this specimen seems to show it to be primitively Cycadean in character.

REPORTS AND PROCEEDINGS.

I.—Geological Society of London.

June 15, 1910.—Professor W. W. Watts, Sc.D., M.Sc., F.R.S., President, in the Chair.

The following communications were read:—

1. "The Natural Classification of Igneous Rocks." By Dr. Whitman Cross, F.G.S.

The author reviews the various sytems of classification which have been proposed. He discusses the origin of the difference of composition of igneous rocks due to: (1) primeval difference, (2) magmatic differentiation, (3) assimilation; and points out that differentiation and assimilation are in a measure antithetical processes.

If the deep-seated magmas of large volume have acquired their various chemical characters in different ways, it appears at once evident that this primary genetic factor cannot be used in classification, unless the characters of different origin can be distinguished in the rocks.

Classification by geographical distribution of chemically different rocks is considered, and the groupings proposed by various writers are discussed; and it is shown that the rocks of the Pacific zone of North America indicate that they possess provincial peculiarities of interest, but that these are not by any means identical with the features emphasized by Becke and others as characterizing the Pacific kindred.

The factors of magmatic differentiation are then reviewed. The aschistic and diaschistic magmas of Brögger and the 'dyke rocks' of Rosenbusch are discussed; and it is contended that certain dyke rocks of Colorado show a notable exception to the rule postulated by Rosenbusch. The conclusion is reached that the sharp distinction between the two 'dyke rock' groups is a purely arbitrary one, resting on an unproved hypothesis.

A discussion on the classification by eutectics follows, and the writings of G. F. Becker and J. H. L. Vogt on this subject are criticized. The view that graphic, spherulitic, and felsitic textures are characteristically eutectic is considered to be incorrect, and it is contended that magmatic classification by eutectics is fundamentally weak, because it rests on hypothesis, because it does not apply to all rocks, and because it does not allow for the entire magma of most rocks. A classification by eutectics may, in the future, be realized; but it seems inevitable that it must be a classification for a special interest, not for the general science of petrography.

The author considers that the distinction between felspathic and non-felspathic rocks which has been so prominent in current systems is not only unnatural, but is in the highest degree arbitrary.

The use of texture is then discussed, and it is shown that classification by occurrence, as determining texture, or by texture, as expressing the broad phases of occurrence, is based on long disproved generalizations made from limited observation. The "American Quantitative System of Classification" is then briefly dealt with, and the following general conclusions are formulated:—

"The scientific logical classification of igneous rocks must apparently be based on the quantitative development of fundamental characters, and the divisions of the scheme must have sharp artificial boundaries, since none exist in Nature.

"Chemical composition is the fundamental character of igneous rocks, but it may be advantageously expressed for classificatory purposes in terms of simple compounds, which represent either rock-making minerals or molecules entering into isomorphous mixtures in known minerals. It is probable that the magmatic solution consists of such molecules, and that the norm of the 'Quantitative System' is a fairly representative set of these compounds.

"The actual mineral and textural characters of igneous rocks are variable qualifiers of each chemical unit, and should be applied as such to terms indicating magmatic character."

2. "The Denudation of the Western End of the Weald." By Henry Bury, M.A., F.L.S., F.G.S.

There are two main theories of Wealden denudation—(1) attributing the removal of most of the Chalk to marine planation; and (2) denying planation and relying solely on subaërial denudation. Professor W. M. Davis's suggestion of a subaërial peneplain forms a sort of connecting link between the two.

The evidence in favour of planation which Ramsay and Topley brought forward is inconclusive, and might plausibly, if it stood alone, be attributed to pre-Eocene causes. On the other hand, Prestwich's arguments against planation are equally weak, while the Chalk plateau to which he draws attention strongly supports Ramsay's views. The distribution of chert is fatal to Professor Davis's hypothesis, and very difficult to account for, except on the marine theory.

In the case of the River Blackwater it can be proved that, long after the Hythe Beds of Hindhead were uncovered, the river-system remained extremely immature, and this affords very strong grounds for the acceptance of the marine hypothesis.

The evidence of the other western rivers is less conclusive, though the Wey and the Mole both provide minor arguments pointing in the same direction. The anomalous position of the Arun, at the foot of the northern escarpment of the Lower Greensand on either side of the Wey, is almost certainly due to comparatively recent captures from the latter river, and affords no ground for assuming a river-system of great age matured on a Miocene peninsula.

There is no proof that any of the existing connexions between rivers and longitudinal folds are of a primitive character, and, on the other hand, there are many alleged examples of transverse disturbances having served as guides to consequent rivers. This again, on the whole, supports the marine hypothesis, especially if, as there are reasons for believing, the longitudinal folds are older than the transverse.

3. "An Earthquake Model." By John William Evans, D.Sc., LL.B., F.G.S.

This model is designed to show the successive conditions that result in an earthquake shock—

(1) Slow relative movement between two extensive portions of the earth's crust lasting over a long period, and causing
(2) a state of strain in the intervening tract, leading to
(3) fracture which relieves the strain and allows
(4) the adjoining portions of the rock on either side to fly back by virtue of

their elasticity, so as to resume as far as possible their original relation to the rock-masses with which they are still connected. This movement of release may give rise to two kinds of periodic disturbance:

(5) short-period vibrations, due to a sudden arrest by an obstacle and constituting the earthquake properly so called, and

(6) a slower backward and forward swing of the rock about the position of equilibrium.

The more important permanent variations in the configuration of the earth's crust in the neighbourhood of the San Andreas fault in the Californian earthquake of 1906 are well shown by the model. This earthquake is regarded as an incident in the slow northward creep of the North Pacific relatively to the adjoining continents, part of the process of adjustment of the earth's crust to the interior—rendered necessary by the expansion of the crystalline rocks of the former on hydration, and the contraction of the latter as the result of cooling and loss of material by volcanic and kindred phenomena.

The President read the following communication received from Mr. S. S. Buckman, F.G.S.:—

May 29, 1910.

"In my paper on certain Jurassic Species of *Ammonites* (Quart. Journ. Geol. Soc., 1910, vol. lxvi, p. 90) I proposed for a new genus the name *Burtonia* (p. 97). With that kind helpfulness which is so distinctive of American scientific workers, Dr. W. H. Dall writes to say that this name is already in use—by Bonaparte for a bird and by Bouvignat for a naiad. I therefore desire to substitute the name *Bredyia* for *Burtonia* in my paper: *Bredyia* is from the River Bredy (pronounced 'Breedy', 'Briddy'), which flows through Burton Bradstock, and its name presumably furnishes the syllable 'Brad'. I wish to record my thanks to Dr. Dall for his kindness.

"The opportunity may be taken to rectify a misprint: in p. 68, l. 7 from the top, *for* 'striking' *read* 'sticking'."

II.—Mineralogical Society.

June 7, 1910.—Professor W. J. Lewis, F.R.S., President, in the Chair.

Arthur Russell: On the occurrence of Phenakite in Cornwall. Phenakite was unknown in the British Isles until the discovery by the author in 1905 of a single specimen at the Cheesewring Quarry, Linkinhorne, Cornwall. In 1906 he collected further specimens, showing numerous small but well-formed crystals, from a tin lode at South Phœnix Mine, Linkinhorne. In an old Cornish collection acquired by him in 1909 he found a specimen with as many as forty fine crystals; it was labelled "Topaz on Quartz from St. Agnes". Phenakite was also recognized on a specimen found about the year 1870 by Mr. J. H. Collins at South Crofty Mine, Illogan, Cornwall. Search at the Natural History Museum and the Museum of Practical Geology brought to light other specimens of phenakite placed under apatite.—Dr. G. F. H. Smith: (1) Phacolite from near Belfast. Two types were described. In the first the crystals were large (about 10–14 mm. across) and much striated, and in the second they were small (about 1–2 mm. across) but with plane faces; in both instances the crystals were twinned about the trigonal axis, the individuals interpenetrating one another, and the forms present were r (10$\bar{1}$1), t (31$\bar{4}$2), e (01$\bar{1}$2), s (02$\bar{2}$1). The measurements accord closely with the data given for chabazite. (2) The Crystalline Form of Nitrogen

Sulphide. Crystals of this rare substance have recently been prepared by Mr. F. P. Burt, University College, London, by sublimation. The constants obtained were $a : b : c = 0{\cdot}8879 : 10{\cdot}8480 : \beta = 90° 23'$, and the observed forms were (100), (010), (001), (110), ($\bar{1}$01), (011), (101), (210), (111), ($\bar{1}$21), the last four being new. The crystals were invariably characterized by polysynthetic twinning about ($\bar{1}$01). A biaxial interference figure with strong positive double refraction was visible through ($\bar{1}$01).—Dr. G. T. Prior and Dr. G. F. H. Smith: On a new Arsenate and Phosphate of Lime and Strontia from the Indian Manganese Deposits. Chemical analysis showed that the mineral approximates to the arsenic analogue of apatite. The crystals were not well formed, but the physical characters as far as they could be determined accord with those of apatite. The name fermorite, after Dr. L. L. Fermor, of the Geological Survey of India, who has made an exhaustive study of the manganese deposits, is proposed for this analogue. The presence of strontium, which has not yet been detected in apatite, is of interest.—L. J. Spencer: A (fifth) List of New Mineral Names.

CORRESPONDENCE.

A CHELONIAN FROM THE PURBECK OF SWANAGE, DORSET.

Sir,—In my article on the above subject (see Geol. Mag. for July, pp. 311–14) the following note was sent in too late for insertion:—

Hooley's *Plesiochelys rectensis* from the Wealden of the Isle of Wight (Geol. Mag., 1900, p. 263) shows a præneural and seven neurals, instead of eight neurals as suggested in the original description. The specimen probably indicates a new genus.

Seeley's *Pleurosternum typocardium*, which was insufficiently characterized in his *Index to Axes, etc., in the Cambridge Museum*, is founded on a specimen of *Glyptops ruetimeyeri*. It is much more oval in outline than my Fig. 1, a difference possibly partly due to sex, but otherwise shows no new features. The protuberances caused by the crushing through of the axillary and inguinal buttresses are quite evident. Seeley's other species, *Pleurosternum sedgwickii*, *cansittardi*, and *oweni*, appear to be typical examples of *P. bullocki*.

D. M. S. Watson.

Victoria University, Manchester.

THE TERM 'LATERITE'.

Sir,—I refuse to plead guilty to the charge advanced by Mr. Scrivenor in your July issue of attempting to force a new definition of laterite on geologists and engineers. I only ask that the word shall be employed for rocks which are chemically and physically allied to that on which it was bestowed by Buchanan.

In dealing with questions of priority of nomenclature we must inquire what was the thing (rock, mineral, or organism, as the case may be) to which the name was first applied, not why it was so applied. Buchanan found a rock widely extended in India which was unlike anything with which he was familiar, and he thought that it

required a name. As bricks were made of it (not because it resembled a brick) he called it laterite, certainly without intending to include under it all materials of which bricks could be made. I admit that he did not know its true chemical composition, but in spite of that it must be accepted as the type of what we ought to call laterite.

As a matter of fact the majority of geologists and of scientific mining engineers are now using the word in this sense, the sense which I and others are defending, and that this is so a recent discussion in the pages of the Transactions of the Institution of Mining and Metallurgy, in connexion with a paper by Mr. G. Morrow Campbell on the "Origin of Laterite", is sufficient evidence. As to the word 'bauxite' I have no objection to its being applied to a laterite exceptionally poor in silica and iron, and therefore suitable for use as a source of aluminium and its compounds, as long as it is understood that it is so employed as a commercial mineral term and not as a rock name. Scientifically, however, it should be restricted to a mineral, if such exist, in which two molecules of water are combined with one of alumina.

We shall all look with interest for the results of Mr. Scrivenor's investigation of the chemical nature of the products of tropical denudation—under whatever name or names he may describe them.

JOHN W. EVANS.

IMPERIAL INSTITUTE.
July 1, 1910.

LATERITE AND BAUXITE.

SIR,—I am glad to learn from Mr. Crook's letter in the May number of the GEOLOGICAL MAGAZINE that I am not alone in holding certain views regarding the term laterite and also the term bauxite, but it is a pity that either side should be led into criticisms that are stronger than the occasion warrants.

I can understand Mr. Crook's surprise that anyone should decline to accept, without question, the new definition of laterite, seeing by what authority it is supported, and I grant that the proposed definition is attractive. But what, in my opinion, has been lost sight of, is that laterite was defined more than a hundred years ago, and that the extension of the term in tropical countries has been based on the early descriptions, the keynotes of which are brick and iron. When an innovation is proposed—for I must with all deference ask still to be allowed to consider this 'aluminous' definition an innovation—the first question is whether it is practicable, the next whether it is necessary. I do not think the change practicable, because the ideas of brick and iron have taken firm root and have led to the term being widely used for ferruginous rocks, useful in public works and in building. As its practicability is denied there is no question of its necessity; but were the change practicable, would the new be better than the old definition? The brick and iron characteristics are easily recognized: the aluminous is not. The word 'laterite' has no etymological connexion with aluminium; it has with brick, and so, indirectly, with iron, since the setting of laterite is dependent, mainly at any rate, on the presence of ferric hydroxide. Both Dr. Evans and

Mr. Crook appear to think—I hope that I am not doing them an injustice—that because the two definitions apply to the same thing, therefore they are the same. This is hardly logical. They emphasize distinct characteristics, scientific and commercial, and are therefore different.

An example illustrating the difficulty, however, will be more to the point than a long argument. In the Federated Malay States the chief crystalline rock is granite, and the mode of weathering is excellently shown by many miles of road sections in hilly country, where the transition from fresh rock to soil can frequently be followed. The rock weathers in situ to a soft mass, red or yellow, sometimes white, in colour, in which one sees round boulders of fresh granite that has resisted decomposition and so formed 'core-boulders'. I have taken a specimen from about midway between the soil and the fresh rock, and after drying have treated it with sulphuric acid for about one hour over a water-bath. The iron and aluminium that went into solution were precipitated as hydroxides, and the aluminium hydroxide separated by KHO and re-precipitated by ammonium chloride. After ignition I obtained over 13 per cent. of alumina, and as I must assume that this alumina exists in the rock as a hydrate or hydrates, the rock falls under the proposed new definition of laterite. It is a weathering product of a crystalline rock containing aluminium hydroxides in a tropical country. But no one here calls it laterite or wishes to do so; it does not harden on exposure, and is therefore of no use as a substitute for brick. It is decomposed granite, and it would be an unnecessary complication to call it anything else, in spite of the interesting fact that a considerable percentage of aluminium hydroxide has been formed during the process of decomposition. Indeed, it may prove that this feature of tropical weathering is so general that it cannot be regarded as characteristic of any one decomposition product, and that, if the presence of aluminium hydroxides is to be the test of laterite, then there will be a difficulty in excluding rocks that have no resemblance to Buchanan's laterite, as, for instance, the china-clay and clay-slate mentioned in my last letter.

We know that the composition of laterites varies with the character of the rock from which it is derived; and I have ventured to propose that, for the sake of simplicity, we should call bauxite certain laterites in India that have been stated to be bauxite. "Laterite is bauxite in various degrees of purity." "These are bauxites in blocks and in powder." I am now told that I am guilty of endeavouring to degrade the term 'bauxite' completely, and that my suggestion is positively harmful; while I am furthermore invited to assert that a mineral of a definite chemical composition, which has not yet been proved to exist, does not exist, and to state what name I propose to give it if it should be proved to exist. The word 'bauxite', Mr. Crook says, must be reserved for a hypothetical mineral of the composition $Al_2O_3 . 2H_2O$, and it may not be used as a rock-name until that hypothetical mineral is proved to be a myth; but there is some plausibility in my suggestion because the term has been used carelessly.

Bauxite was discovered in France, and France possesses a mineralogist who cannot be accused of using mineralogical terms